Faculty of Agriculture
Soils and Water Department

IMPLICATION OF USING LOW QUALITY WATER ON SOIL AND PLANTS GROWN IN EAST DELTA REGION

BY

Mahmood Abdullah Ali
B.Sc. Agric.(Soil sci.), Basrah University, Iraq (1995)

A Thesis
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Under Supervision of:

Prof. Dr. Abo-El-Nasr H. Abdel-Hameed …………………………….
Emeritus Professor of Soil Science, Faculty of Agriculture, Benha University

Prof. Dr. Ihab Mohamed Farid Abdel-Samie ……………...…………..
Professor of Soil Science, Faculty of Agriculture, Benha University

Dr. Mohamed Hassan Hamza Abbas …………………………..
Associate Professor of Soil Science, Faculty of Agriculture, Benha University

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<u>This Thesis for M.Sc. degree has been approved by:</u>

Prof. Dr. Abo-El-Nasr H. Abdel-Hameed ……………………....

Emeritus Professor of Soil Science, Faculty of Agriculture, Benha University

Prof. Dr. Ayman M. El-Ghamry ……………………..…

Professor and Head of soils Department, Faculty of Agriculture, Mansoura University

Prof. Dr. Ihab Mohamed Farid Abdel-Samie …………………….

Professor of Soil Science, Faculty of Agriculture, Benha University

Dr. Mohamed Hassan Hamza Abbas ……………………..

Associate Professor of Soil Science, Faculty of Agriculture, Benha University

Dr. Maha Mohamed El Sayed Ali ……………………........

Associate Professor of Soil Science, Faculty of Agriculture, Benha University

Date of Examination: 4 /5 /2017

Dean	**Vice dean of graduate studies and research**
Prof. Dr. Mahmoud M. Eraqi	**Prof. Dr. Naser Khames El-Gizawy**

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1. INTRODUCTION

Water is one of the basic requirements for the sustenance of life. Water is the fundamental element for sustainable and integrated development in Egypt. Now, Egypt is reaching its limits of available water and Egypt will have to face variable water supply conditions. Rapid growth in urban population and water demand in the last few years have resulted in greatly increased water supply provision. Due to the scarcity of freshwater, farmers have no other option left but to grow their crops using non-conventional sources of water. Moreover, the economics of water use and its future on the long run require searching for alternatives and determining the water resources available at present and additional resources we can obtain in the future.

The use of wastewater for irrigation is a viable option to reduce the use of water resources and to increase the supply of water for various purposes. Among various non-conventional sources, treated municipal wastewater is an important source of water for irrigation in arid and semiarid regions. It may also serve as a promising source of plant nutrients such as nitrogen, phosphorous, other nutrient elements and organic material that has a potential to increase soil productivity under arid conditions. Utilization of treated wastewaters for agricultural irrigation, in addition to being a low-cost available water source, also minimizes effluent disposal problems and hence environmental contamination, and reduces the need for the input of chemical fertilizers. The use of treated wastewater for crop irrigation has been one of the possible ways out of a looming water crisis.

The current study aims at investigating the consequences of using the wastewater of Belbais drain for complimentary irrigations of wheat plants grown in soils nearby the drain in the North East region of Egypt.

Four elements were selected in the current study. They are three nutritional elements (nitrogen, phosphorus and boron) and a non-nutritional one (arsenic). These elements were determined in the Belbais drain water in different locations along the drain. Also, samples of soils and wheat plants were collected from the same locations for determination of the same elements.

2. REVIEW OF LITERATURE

2.1. Wastewater and environment

In Egypt and many developing countries, wastewater has long been used as a source of nutrients for plants **(Jiménez and Asano, 2008)**. However, using such water for irrigation purposes might bring many contaminants to soils such as *salmonella* and *vibrio* **(Grimes *et al*., 1984),** antibiotics **(Karthikeyan and Meyer, 2006; Watkinson *et al*., 2007)**, diagnostic agents, disinfectants and excreted non-metabolized pharmaceuticals by patients **(Emmanuel *et al.*, 2005)**, faecal coliforms and helminth eggs **(von Sperling and Augusto de Lemos Chernicharo, 2002)** and heavy metals **(Kurniawan *et al*., 2006)**.

This wastewater might comes from different sources e.g. "domestic effluent consisting blackwater (excreta, urine and faecal sludge, i.e. toilet wastewater), greywater (kitchen and bathing wastewater), industrial and agricultural effluents, hospitals, and stormwater" **(Raschid-Sally and Jayakody, 2008)**, beside of the industrial effluents **(Giorgi and Malacalza, 2002)**. This water finds the way to the surface and ground water **(Phillips and Chalmers, 2009)** causing serious environmental hazards

(McCunney, 1986). Accordingly, serious measures should be taken to control this point sources of pollution **(Taebi and Droste, 2004)** mainly through introducing wastewater treatment technologies to remove pollutants **(Chen *et al*., 2006)** for possible reuse **(Lin and Chen, 1997)** on one hand and prevent further pollution of water bodies **(Asano *et al*., 2007)** on the other hand.

2.2. Water scarcity and wastewater use in agriculture

Water is a scarce commodity in the Middle East and North Africa and its availability is declining to a crisis level. The reuse of wastewaters for purposes such as agricultural irrigation can reduce the amount of water that needs to be extracted from environmental water sources **(Heidarpour *et al*., 2007)**. However, irrigation with treated wastewater TWW is not free of risk both to crop production and soil environment **(Bhardwaj *et al*., 2007).** Water scarcity is one of the main topics in the Mediterranean region. This probably arises from the relative uneven distribution of rainfall, high temperatures, besides increasing demands for irrigation water **(Loutfy, 2011)**. It is worthy to mention that the problem of water scarcity grow up to become an international problem **(Shanableh and Rahman, 2014)**. It has become one of the important issues in the coming century threatening food security and "this might affect health and mortality besides being an important prospect for peace" **(Macedonio *et al*., 2012)**.

Nowadays, due to the constraint in availability of the freshwater for irrigation, waste water especially sewage water is being used for irrigation of agriculture fields.

The reuse of wastewater finds increased application in irrigation but the presence of toxic elements and microorganisms limits its use for irrigation purpose **(Tripathi *et al*., 2014 and Saha *et al*., 2015)**. Shortage of fresh water and wide spread water pollution are current realities faced in many parts of the world. Particularly in arid and semiarid regions, partially treated and untreated wastewater discharged into rivers form the major cause for various environmental problems like spreading of diseases, toxins entering the food chain through fishes, eutrophication, and increase in biological oxygen demand and whereby, there will be a reduction in the number of aquatic creatures (**Rai and Tripathi 2007**). Wastewater is used in agriculture, rangelands, forests, parks, and golf courses in many parts of the world (**Al-Jamal *et al*., 2002**).

Wastewater irrigation is a common reality in Africa, Asia and Latin America. In Egypt, it is becoming more widely recognized that the use of untreated wastewater for the irrigation of vegetables is a widespread practice in peri urban areas. Many farmers, especially those in urban areas, use wastewater through surface irrigation method because it is freely available and in abundance, during droughts; they contain nitrates and phosphates that act as an effective fertilizer (**WHO, 2006**).

Accordingly, many countries were forced towards using non conventional sources **(OhIsson, 2000; Pereira *et al*., 2002 and Bixio *et al*., 2006)** to meet the increased demand of agricultural production **(Ambika *et al*., 2010).** Among the various non conventional sources, wastewater reuse or reclamation serves as an important source of irrigation **(Chu *et al.*, 2004 and Bixio *et al.*, 2006)**. Re-use of wastewater for agricultural irrigation is a response to the scarcity of water in the world (**Ensink *et al*., 2008**). Wastewater is a combination of domestic effluents, industrial effluent, storm water and water from commercial institutions; that are released into the common sewerage network of a city **(Kanyoka and Eshtawi, 2012)**. Reclamation and reuse of wastewater reduces the demand for fresh water resources (**Mojiri, 2011 and Shanableh and Rahman, 2014)** in countries that suffer from different levels of water scarcity **(Loutfy, 2011).** Such treated municipal wastewater is an important source of water for irrigation in arid and semiarid regions **(Abdel-Shafy and Abdel-Sabour, 2006, Amin, 2011 and Loutfy, 2011)** and could completely substitute fresh water in irrigation (**da Fonseca *et al*., 2005).** Thus, there is an actual need to use low quality water in agriculture as an innovative alternative option to augment traditional fresh water supply **(Abdel-Dayem, 2000).**

2.3. Wastewater is a source of plant nutrients

Wastewater may have beneficial effect when appropriately used as irrigation in agriculture. It may act as source of water and nutrient **(Shanableh and Rahman, 2014).** The use of wastewater for irrigation adds natural fertilizers to the soil and enriches top soil with nutrients **(Peasey *et al*., 2000)**. Nutrients in treated wastewater that are important to agriculture include nitrogen, phosphorus, potassium, zinc, boron and sulphur **(Asano and Levine, 1998)**. Irrigating soils with wastewater increased soil nitrogen, phosphorus and potassium (**Rahmani, 2007**). Treated municipal wastewater is an important source of water for irrigation in arid and semiarid regions. It may also serve as a promising source of plant nutrients such as N, P and K and organic material that has a potential to support plant growth and increasing soil productivity under arid conditions **(Angin *et al*., 2005, Ozturk *et al*., 2011 and Afifi *et al*., 2011)**, and suggesting its use as a low-grade cheap fertilizer and partial substitution of chemical fertilizers in agriculture (**Ali, 2010, Kharche *et al*., 2011 and Singh *et al*., 2012**).. Utilization of treated wastewaters for agricultural irrigation, in addition to being a low-cost available water source, also minimizes effluent disposal problems and hence environmental contamination, and reduces the need for the input of chemical fertilizers.

The different physico-chemical and biological parameters of sewage water were studied and observed considerable variation among different districts and in different seasons, and also reported that the effluent has the capacity to contribute cumulative nutrients (N, P, K, Zn, Fe and Cu) of approximately 56.4 tons day^{-1} (**Yadav *et al*., 2002)**. Treated wastewaters contain higher levels of plant nutrients compared to potable water **(Bernstein, 2006)**.

The use of sewage effluents (after primary sedimentation in exposed basins) of Cairo city in irrigating a loamy sand soil i.e. El-Gabal El-Asfar area has markedly increased both total and soluble nitrogen, available phosphorus in soil, and its level of water soluble boron and the surface layers (0-25cm) contained higher amounts of elements than the subsurface (25-50cm) ones (**El-Nennah *et al*., 1982**).

2.3.1 Nitrogen

Irrigation with wastewater provides some of the demanded nitrogen and other nutrients for plants (**da Fonseca, *et al*., 2005)**. Nitrogen is the main nutrient limiting crop production **(Fageria and Baligar, 2005).** Almost, wastewater contains 40 g m^{-3} total nitrogen, resulting from the decomposition of protein waste **(Ferguson *et al*., 2003).**

Nitrogen is a plant nutrient and stimulates crop growth. Natural soil nitrogen or added fertilizers are the usual sources, but nitrogen in the irrigation water has much the same effect as soil-applied fertilizer nitrogen. The most readily available forms of nitrogen are nitrate and ammonium but nitrate (NO_3-N) occurs most frequently in irrigation water. Ammonium-nitrogen is seldom present in excess of 1 mgL^{-1} unless ammonia fertilizer or wastewater is being added to the water supply. The concentration in most surface and groundwater is usually less than 5 mg L^{-1} NO_3-N but some unusual groundwater may contain quantities in excess of 50 mg L^{-1}. Wastewater, is known to be high in nitrogen with values ranging from 10 to50 mgL^{-1} (1 mgL^{-1} NO_3-N = 1 kg N/1000 m^3 of water) **(FAO, 1985)**. The sewage water has a high nutrient load suspended solids and dissolved nitrates (**Ali, 2010).**

Wang *et al*., (2007) stated that the wastewater contains high levels of nitrate and other nutrients. Using this waste water to irrigate the fields can be a suitable disposal method. Field application will reduce fertilizer costs, but it can also cause underground water contamination if over-applied to the field. Their study revealed that both water and nitrogen positively affect crop yields, replacing some wastewater with fresh water and nitrogen fertilizer.

Probably, irrigation with treated wastewater was able to save fertilizers up to 50kg urea and 50kg of di-ammonium phosphate during cultivation of one acre of crop annually **(Kumar *et al*., 2014).** It was found that the total nitrogen increased in soils by 18.4% with the long-term wastewater irrigations, average concentrations in the surface layer of the soil were higher than those in the subsurface one, probably due to variations in the organic matter content and microbial population (**Yao *et al*., 2013**). It is estimated that 1000 m^3 of municipal wastewater used to irrigate one hectare can contribute 16-62 kg total nitrogen **(Qadir *et al*., 2007)**. Build up in total N up to 2908 kg ha^{-1} in the surface soil layer (0-15 cm) were found with long-term irrigated with wastewater **(Yadav *et al.*, 2002)**. The reuse of sewage for irrigation has led to increase the content of each of the organic carbon and total nitrogen (**Khai *et al*., 2008**).

The use of sewage water in irrigation led to increase in the total N in the soil after harvesting, due to the high concentration of N and organic compounds in the sewage water **(Afifi *et al*., 2011)**. The N content of a forest soil at different depths clearly increased as a result of the irrigation with sewage water and the highest N value (462 $mgkg^{-1}$) was at a depth of 30-60 cm (**El-Khateeb *et al*., 2012**).

Treated wastewater is a good source of N for the grown plants (**Alghobar and Suresha, 2015)**; however, excess N in water can cause eutrophication **(Zhu *et al*., 2008).**

2.3.2 Phosphorus

Phosphorus is another macro nutrient limiting crop production especially during the early stages of growth **(Grant *et al*., 2005)**. Phosphorus is one of the most important major nutrients required for the growth and development of crop plants. It plays a vital role in virtually every plant process like photosynthesis, energy storage and transfer, stimulating root development and growth, giving plant rapid and vigorous start, and encouraging earlier maturity and seed formation. It also has a significant role in sustaining and building up of soil fertility, particularly under intensive system of agriculture **(Lines-Kelly, 2002 and Lemanowicz *et al*., 2013)**. Phosphorus is mainly supplied to plants as mineral fertilizers derived from phosphate rock, which is a non-renewable resource and will be depleted within 50–100 years **(Cordell *et al*., 2009)**.

Almost, wastewater contains 15 g m^{-3} phosphate **(Ferguson *et al*., 2003)**. Treated wastewater is also a source of phosphate for the grown plants, yet the presence of large quantities of phosphate in wastewater might cause eutrophication **(de-Bashan and Bashan, 2004)**. It was found that total phosphorus increased in soils by 8% with the long-term wastewater irrigations (**Yao *et al*., 2013).**

Build up in total P (2115 kg ha^{-1}), available P (58 kg ha^{-1}), in the surface soil layer (0-15 cm) were found with long term irrigated with wastewater **(Yadav *et al.*, 2002)**. It is estimated that 1000 m^3 of municipal wastewater used to irrigate one hectare can contribute 4-24 kg phosphorus (**Qadir *et al*., 2007)**.

The use of sewage water in irrigation provides essential nutrients such as N and P to plants grown on the soil and improves soil fertility (**Ladwani *et al*., 2012**). The use of sewage water in irrigation led to increasing the available P content in the soil after harvesting, due to the high concentration of P and organic compounds in the sewage water **(Afifi *et al*., 2011)**. The P content of a forest soil at different depths clearly increased as a result of the irrigation with sewage water and the highest P concentration (34.5 mg kg^{-1}) was at 30 cm soil depth (**El-Khateeb *et al*., 2012**).

2.3.3 Boron

Boron is also an essential element for plant growth. High B concentrations may occur naturally in the soils of arid and semi-arid areas arising from various anthropogenic sources such as mining, fertilizers, or irrigation water (**Camacho-Cristobal *et al*., 2008**).

Boron is needed in relatively small amounts, however, and if present in amounts appreciably greater than needed, it becomes toxic. For some crops, if 0.2 mg L^{-1} boron in water is essential, 1 to 2 mg L^{-1} may be toxic. Surface water rarely contains enough boron to be toxic. Boron problems originating from the water are probably more frequent than those originating in the soil **(Hassanli and Kazemi, 2012).** Continued irrigation with water containing concentrations of B greater than 4 mg L^{-1} may pose a hazard for some B-sensitive crops. However, the use of irrigation water with high levels of B may be suitable for certain crops **(Bastías *et al*., 2004)**.

There is a convincing evidence for a direct effect of B toxicity on nitrate assimilation. Boron excess inhibited NO_3 reduction decreasing N organic concentration, but increasing NH_4 assimilation **(Cervilla *et al*., 2009).**
In soils, boron concentrations ranging from 10-300 mg kg^{-1} of soil, whereas boron concentrations in surface water range from 0.001-2 mg L^{-1}.

Boron deficiency, in wheat, results in an increase in number of open spikelets and a decrease in the number of grains per spike **(Furlani *et al*., 2003)**. On the other hand, excess boron can also be toxic to plants **(FAO, 1985).** Thus, wastewater reuse for agriculture needs to be planned with attention to target crops and existing water delivery methods.

2.4. Arsenic in soil and water

Arsenic is a chemical element naturally present in the environment. Human activities has increased its content in some soils, its content in plants increases with increasing content in the soil **(Peryea, 2001 and Garelick *et al*., 2008)**. Arsenic is a naturally occurring toxic element that exists in a wide range of minerals. Uncontaminated soils usually contain 0.1-40 mg kg^{-1} of arsenic, with lowest concentrations in sandy soils and those derived from granites, whereas larger concentrations are found in alluvial and organic soils **(Mandal and Suzuki, 2002).** The arsenic in soil may be occurring as a result of the application of arsenic-containing pesticides or sludge. 80% of the arsenic is added to the soil and water as a result of the use of agricultural pesticides (**Bligh and Mollehuara, 2012**). Arsenic is largely immobile in agricultural soils; therefore, it tends to concentrate and remain in upper soil layers indefinitely (**Sanok *et al*., 1995**).

Arsenic may be released to water from the natural weathering of soil and rocks, and in areas of volcanism. Arsenic may also leach from soil and minerals into groundwater. Anthropogenic sources of arsenic releases to water include mining, nonferrous metals, especially copper, smelting, waste water, dumping of sewage sludge, coal burning power plants, manufacturing processes, urban runoff, atmospheric deposition and poultry farms (**Nriagu and Pacyna 1988 and Garbarino *et al*. 2003**).

The behavior and availability of arsenic in the soil are influenced by soil pH, content of organic matter, clay content, iron oxides, calcium carbonate and cation-exchange capacity (**Song *et al*., 2006; and Kandakji *et al*., 2015**). Phosphorus is an important factor determining the uptake of arsenic by some plant species (**Otte *et al*., 1990**). Inorganic arsenic inhibits phosphate uptake by plant, thus, its presence in soils and water is toxic to plants **(Vithanage *et al*., 2012).**

The toxicity of arsenic in soil and water are increasingly at risk around the world **(Mirza *et al*., 2014)**. The use of ground water contaminated with arsenic for years to irrigate rice crop has increased the level of arsenic in the soil as well as the concentration of arsenic in all parts of the plant. However, arsenic concentration in rice grain did not exceed the maximum permissible limit of 1.0 mg As kg^{-1} **(Abedin *et al*., 2002).** Rice yield decreased gradually from 7-9 Mg ha^{-1} to 2-3 Mg ha^{-1} with increasing soil arsenic concentration. As a result of long-term irrigation water contaminated with arsenic **(Panaullah *et al*., 2009)**. Arsenic uptake by rice crop depends on some soil properties, such as pH, redox potential, and phosphorous content, hence arsenic content of grain is not significantly correlated with the total arsenic content in soil **(Kang, 2016)**.

Duxbury and Panaulla (2007) showed that irrigation wastewater containing arsenic effect on wheat plant. Wheat crop and wheat yields were negatively correlated with soil arsenic, also, As was the cause for reduced wheat yield as the availability of As is low under the aerobic soil conditions of wheat growth. Because irrigation water deposits both As and P in soils and that the relationship between yield and soil As and P was due to zinc deficiency in wheat. Grain and straw As concentrations increased progressively with increasing water As, to a maximum of 0.1 and 3.3 mg kg^{-1} at the highest soil As level.

Mojiri and Abdul Aziz, (2011) studied the effect of municipal wastewater on accumulation of heavy metals in soil and wheat (*Triticum aestivum* L.). They found higher concentrations of heavy metals such As in wheat plants treated with municipal wastewater. They also observed that accumulation of metals in roots is more than in shoots.

Liu *et al*. (2012) found that wheat yields were elevated at low rates of arsenic addition (< 60 mg/kg) but reduced at high rates of arsenic concentrations (80–100 mg/kg), while the growth of rape hadn't showed significant responses to arsenic addition. Phosphorus concentrations in wheat at jointing and ear sprouting stages increased with increasing soil arsenic concentrations and these increases were assumed to contribute a lot to enhanced growth of wheat at low arsenic treatments. Arsenic concentrations in wheat and rape grains did not exceed the maximum permissible limit for food stuffs of 1.0 mg/kg.

Shad *et al.* (2014) carried out an experiment to investigate the effect of arsenic present in domestic sewage water on a wheat irrigated with domestic sewage water. Results showed that arsenic concentration in soil, the values of transfer factor for Na, K, Mg, Ca and As from soil to shoots was affected significantly by sewage water.

2.5. Effect of wastewater on plant growth and uptake of same nutrients

Many reports (**Omran *et al*., 1988; Zaghloul and Atta-alla, 2001; Lal *et al*., 2003 and Rija *et al*., 2005**) stated an increase in plant growth and productivity due to the high nutrient content in the sewage water.

Zaghloul and Atta-alla (2001) carried out an experiment with secondary treated sewage effluent, sewage sludge and cement dust on Gladiolus and found that the sewage water irrigation resulted in earlier flowering and increased fresh weight of corns compared with river water irrigation.

Al-Jaloud and Hussain (2003) carried out an experiment to determine yield and efficiency of water use for wheat crop with and without nitrogen fertilizer under different types of irrigation waters. They found that under treated effluent irrigation, a higher grain yield of wheat crop can be achieved with low rates of nitrogen application if the crop is irrigated with treated effluent containing nitrogen in the range of 20 mg L^{-1} and above. Overall, there exists a great potential for better water resources management if an optimum dose of nitrogen fertilizer is applied under different types of irrigation waters containing varying amounts of nitrogen. Wastewater can have a positive effect on soil and eventually plant growth, due to its being rich in organic matter and nutrients (**Mohammad and Ayadi, 2004 and Ghanbari *et al*., 2007**). It was reported that irrigation with wastewater increased the uptake of macro and micro-nutrients by cauliflower and red cabbage plants i.e. N, P, K, Ca, Mg, Na, Fe, Mn, Zn, Cu resulting in further significant increases in their yields (**Kiziloglu et al., 2008).**

Rija *et al*., (2005) in their study of sewage irrigation on plants like *Vigna radiata*, *Cicer arietinum* and *Lens culinaris* found that an increase in total protein, carbohydrate and chlorophyll contents in *L. culinaris* and *C. arietinum* leaf samples. A significant increase in the biochemical constituents like protein, carbohydrate and aminoacid contents in the fodder grass irrigated with sewage water during summer season was reported by **Girisha *et al*. (2007)**. **Kiziloglu *et al*. (2007)** in their study on cabbage plants irrigated with wastewater reported that the wastewater and preliminary treated wastewater significantly affected the plant nutrient contents after one year. Wastewater application increased yield, macronutrients and micronutrients of cabbage. The crop yield and quality of seven crops such as celery, wheat, maize, millet, apples, rapeseed and yellow beans did not vary significantly between treated and untreated sewage irrigated crops (**Wang *et al.*, 2007**).

The use of wastewater in irrigation increased plant growth, photosynthesis and yield of the grown crop (**Masto *et al*., 2008 and Tak *et al*., 2010)**. **Mojiri *et al*. (2013)** studied the impact of irrigation with urban wastewater on *Lepidium sativum* in an arid region. They reported an increase in root and shoot length**.** The use of wastewater in irrigation not only increased leaf number, leaf area, plant dry matter, photosynthetic rate, total chlorophyll content, 1000 seed weight and seed yield by giving significantly higher values than ground water, but also saved the extra dose of fertilizers, thus serving the twin objectives of saving fresh water as well as saving the extra dose of fertilizers **(Tabassum *et al*., 2013).** Crop growth in terms of photosynthesis, net assimilation rate and dry matter production significantly increased in sewage-irrigated land compared to bore well irrigated land **(Salakinkop and Hunshal, 2014).**

2.6. Effect of wastewater on soil chemical characteristics

The impact of wastewater irrigation on soil depends on various factors i.e. soil properties, plant characteristics and sources of wastewater **(Hussain *et al.*, 2002).**

Effects of municipal wastewater treatments on chemical properties of saline soil, showed an increase in EC, OM, but a decrease in soil pH **(Mapanda *et al.*, 2005, Mahallapa *et al.*, 2010 and Amin, 2011).**

Kiziloglu *et al*. (2008) investigated the effects of untreated and treated wastewater irrigation on some chemical properties of cauliflower (*Brassica olerecea* L. var. *botrytis*) and red cabbage (*Brassica olerecea* L. var. *rubra*) grown on calcareous soil in Turkey. Their results showed that the application of wastewater increased soil salinity, organic matter, exchangeable Na, K, Ca, Mg, plant available phosphorus and microelements, and decreased soil pH. **Masto *et al*. (2008)** found that using sewage water in irrigation increased the clay content in soils to 18–22.7% thus improved the fertility status of soils.

Soil irrigated with wastewater caused an increase in the EC, OM, but it caused a decrease in the soil pH (**Mojiri and Jalalian, 2011**). **Mojiri *et al*. (2013)** studied the impact of urban wastewater on soil properties in an arid region. They found an increase in the electrical conductivity (EC), organic matter (OM), and heavy metals due to wastewater irrigation.

Wastewater irrigation significantly affected the soil chemical properties, especially at a 0–30 cm soil depth, and the plant nutrients. The application of wastewater increased the soil salinity, organic matter, exchangeable Na, K, Ca, Mg, plant available P and microelements and decreased the soil pH **(Khaled and Muhammad, 2015).**

2.6.1. Organic carbon

Long-term sewage irrigation increased the soil organic matter content **(Bao *et al.*, 2014)**. It is worthy to mention that reuse of wastewater for 80 years of irrigation increased organic C contents in soil by 2.5-fold (**Friedel *et al*., 2000**). Also, an increase in organic carbon content ranging from 38 to 79% was found in sewage-irrigated soils as compared to well water-irrigated ones **(Rattan *et al*., 2005).** Using treated sewage water on sandy soil could improve soil organic content **(Abdel-Shafy and Abdel-Sabour, 2006)**.

Using sewage water in irrigation increased organic carbon to 0.51–0.86% (**Masto *et al*., 2008)**. Moreover, **Abdel-Shafy and Abdel-Sabour (2006)** found an increase in organic matter content ranging from 17% to 30% in sewage-irrigated soil samples as compared to well water-irrigated ones.

Singh *et al*. (2012) found an increase in the organic carbon content of the soils irrigated with sewage water compared to those irrigated with ground water and it helps to improve the fertility status of the soil. Treated sewage water increased significantly the soil organic carbon (1.6 g kg^{-1}) **(Ghosh *et al.*, 2012).**

Irrigation with wastewater increased the soil organic carbon content in surface and subsurface layers from 0.6 and 0.3% respectively in 1981 to 1.1 and 0.7% respectively in 2010 (**Mollahosseini, 2013**).

The levels of organic carbon in the soil increased significantly with depth because of increasing rates of irrigation **(Khaled and Muhammad, 2015)**. On the other hand, Consequences of irrigating soils with wastewater increased soil organic matter content (**Morugán-Coronado *et al.*, 2013 and Yao *et al.*, 2013)**. The organic matter in wastewater can improve soil aeration, infiltration rate, water storage, cation exchange capacity (CEC) and decrease the potential for soil erosion and increase the population of organisms which promote plant growth (**Tozé, 2006; Corwin and Bradford, 2008 and Arienzo *et al.*, 2009**).

High addition of organic matter due to wastewater irrigation under anaerobic conditions developed a build-up of soil organic carbon due to the reduced organic carbon decomposition and therefore, the long-term wastewater irrigation can be a good means of carbon sequestration in soils (**Yadav *et al*., 2002 and Dheri *et al*., 2007)**.

2.6.2. Soil pH

Wastewater irrigated soils contain higher organic carbon and nitrogen levels which could promote microorganisms activity to break up organic nitrogen molecules into mineral nitrogen and H^+ ions. Also, wastewater itself may carry H^+ ions into irrigated soils. These to aspects resulted in lower pH values in wastewater irrigated soils (**Yao *et al*., 2013**).

Irrigation with wastewater decreased soil pH (**Mohamed and Mazahreh, 2003; Rattan *et al*., 2005; Rusan *et al*., 2006; Dheri *et al*., 2007; Gwenzi and Munondo, 2008; Mojiri, 2011 and Mollahoseini, 2013**). In this concern, sewage irrigation resulted in soil pH dropped by 0.38 units (**Rana *et al*., 2010 and Al- Omron *et al*., 2011**). This might beneficially improve the plant growth (**Yao *et al*., 2013).** Effects of municipal wastewater treatments on chemical properties of saline soil showed a decrease in soil pH (**Mapanda *et al*., 2005, Mahallapa *et al*., 2010 and Amin, 2011).**

Mohammad and Mazahreh (2003) noticed a decrease in soil pH due to presence of high content of ammonium in wastewater**.** They attributed the decrease in soil pH with the wastewater application to the oxidation of different organic compounds and the nitrification of the resulted ammonia. **Rattan *et al*., (2005**) also noticed that a 20 year long term experimentation using sewage water for irrigating crops revealed a decrease in the soil pH by 0.4 unit down the initial pH value. **Dheri *et al*., (2007)** noticed a decrease in soil pH irrigated with wastewater. The production of organic acids due to the anaerobic decomposition of organic matter is considered a principle cause for the reduced pH in the soil that is irrigated with wastewater.

Treated sewage water resulted in slight decrease in soil pH (**Ghosh *et al.*, 2012**).

On the other hand, many reports **(Saravanamoorthy and Ranjitha-Kumari, 2007; Khai *et al.*, 2008** and **Khurana and Singh, 2012)** stated an increase in soil pH irrigated with wastewater. The increase in the pH of the surface soils irrigated with mixed domestic and industrial effluents attributed to the high content of basic cations such as Ca^{2+}, Mg^{2+} and Na^{+} in these effluents that accumulated for a long period time in the surface soil layer **(Saravanamoorthy and Ranjitha-Kumari, 2007)**. An increase in soil pH irrigated with wastewater by approximately 0.3 unit up the initial pH value (**Khai *et al.*, 2008)**. **Khurana and Singh (2012)** found that a 50 year long-term study of using textile industry effluents in irrigation revealed a 0.4 unit increase in the surface soil pH over that of the soil irrigated with groundwater.

2.6.3. Soil salinity

Soil irrigated with waste-water caused an increase in the electrical conductivity (EC) and total Na (**Mojiri and Jalalian, 2011; Mojiri *et al.*, 2013 and Khaled and Muhammad, 2015**). High concentration of cations such as Na^{+} and K^{+} in wastewater led to an increase in the electrical conductivity (EC) and exchangeable Na and K in the soils irrigated with these water (**Khai *et al.*, 2008**).

Application of untreated and treated wastewater to the calcareous soil in Turkey increased soil salinity **(Kiziloglu *et al*., 2008)**. Also, the application of sewage water to the calcareous soils for 2 years caused a slight increase in the electrical conductivity (EC) and concentration of Na^+ ion in these soils compared to those irrigated with groundwater **(Morugan *et al.*, 2009)**. Wastewater irrigation significantly increased the soil salinity, and the exchangeable Na, K, Ca and Mg, especially at a 0–30 cm soil depth (**Khaled and Muhammad, 2015**).

On the other hand, the use of wastewater for irrigation did not adversely affect the soil salinity, the soil salinity level remained normal indicating no threat to soil quality and hence could be suitable for crop production (**Abegunrin, *et al*., 2013**). **Mollahoseini, (2013)** investigated the long term effect of irrigation with wastewater on the electrical conductivity (EC) of the soil and found that the EC of the topsoil did not show any change from 1981 to 2010 while that of the subsoil changed from 1 to 1.6 dS m^{-1} in this time period. **Yao *et al*. (2013)** reported that no significant differences in the salinity between the soils irrigated with wastewater and the control soil.

2.6.4. Specific ions and sodicity

Soluble cations and anions, electrical conductivity (EC), sodium adsorption ratio (SAR) increased in soil as a result of irrigation with drainage water (**Zein *et al.*, 2002 and EL-Hady, 2007**). Irrigation with alkaline and sodic industrial waste-water results in black alkali formation at the surface, the soil became sodic, with an exchange complex dominated by sodium (**Sou/Dakouré *et al.*, 2013**).

On the other hand, domestic wastewater irrigation applied for a season had no significant effect apart from, slight changes in salt solubility and alkalinity on a clay soil with sewage wastewater irrigation **(Singh *et al*., 2012).** Concentrations of Na^+ and Cl^- did not show any significant difference in soils irrigated with sewage water, whereas, concentrations of Ca^{2+}, Mg^{2+}, and SO_4^{2-} ions changed significantly in sewage water applied sites **(Alghobar and Suresha, 2015).** The use of wastewater for irrigation did not adversely affect the soil, the soil salinity level remained normal and the sodium levels indicated by the sodium adsorption ratio (SAR) were below the critical level of 13, indicating no threat to soil quality and hence could be suitable for crop production **(Abegunrin *et al*., 2013). Freire *et al*., (2014)** found that the relationship between soluble As and soil properties indicated that iron oxides and organic matter content were the variables most closely related to the reduction of the As solubility, while pH and $CaCO_3$ increased As solubility in the soil solutions. Toxicity bioassays showed significant differences between soils depending on their properties, and a significant increase in the highly carbonate samples (between 15 and 25 mg kg^{-1}).

2.6.5. Calcium Carbonate

Application of wastewater to the calcareous soils decreased the soil $CaCO_3$ content. A significant reduction in the soil $CaCO_3$ content occurs in sewage wastewater irrigated soils may be attributed to the decrease in soil pH and the production of organic acids due to the anaerobic decomposition of organic matter, resulting in the solubilization of $CaCO_3$, thereafter it may be leached faraway the root zone (**El-Araby *et al*., 2006**). In Egypt, the soils irrigated with wastewater had a lower $CaCO_3$ content compared to the soils irrigated with ground water and the surface soil $CaCO_3$ content decreased 1.42% with the use of wastewater for irrigation (**El-Hady, 2007**).

2.7. Effect of wastewater on soil microorganisms

Wastewater irrigated soils contain higher organic carbon and nitrogen levels which could promote microorganisms activity to break up organic nitrogen molecules into mineral nitrogen. Soil fertility is greatly influenced by the activities of micro-flora present in it and any alteration or contamination of soil will affect the micro-flora. Due to the scarcity of ground water, farmers are using raw sewage water more frequently for irrigation. This may affect the soil micro-flora as it contains many toxic materials and pathogens. **Das *et al*. (2003)** indicated that the use of raw sewage water directly is harmful to the growth of heterotrophic soil micro-flora, which are responsible for the proper breakdown of soil organic matter for better plant nutrition. The organic materials in wastewater can improve soil aeration, infiltration rate, water storage, cation exchange capacity (CEC) and decrease the potential for soil erosion and increase the population of organisms which promote plant growth (**Tozé, 2006; Corwin and Bradford, 2008 and Arienzo *et al.*, 2009**).

3. MATERIALS AND METHODS

3.1. Area of study

Belbais drain is the main drain of wastewater from Cairo **(Taylor *et al.*, 1993)** carrying sewage and industrial wastewaters (treated and untreated) for 60 km **(Stahl *et al.*, 2009)** serving 39228 ha and discharging the water into Bahr El Baqr drain **(Lovelady *et al.*, 2009)**. Arable lands nearby the drain are mainly short of fresh water for their irrigation **(Hamed *et al*., 2011)** and frequently use the drain's water for complimentary irrigation **(Pereira *et al*., 2002 and Ibrahim *et al*., 2016)**. Ten locations were selected along Belbais drain with approximately 5 km between each two subsequent for water sampling, as shown in Figure 1. Soil and wheat samples were also collected from the arable lands at the aforementioned locations in April 2015 to investigate the implications of using such water for complimentary irrigations on accumulation of NO3-N, P, B and As in soils and the above-ground plant parts.

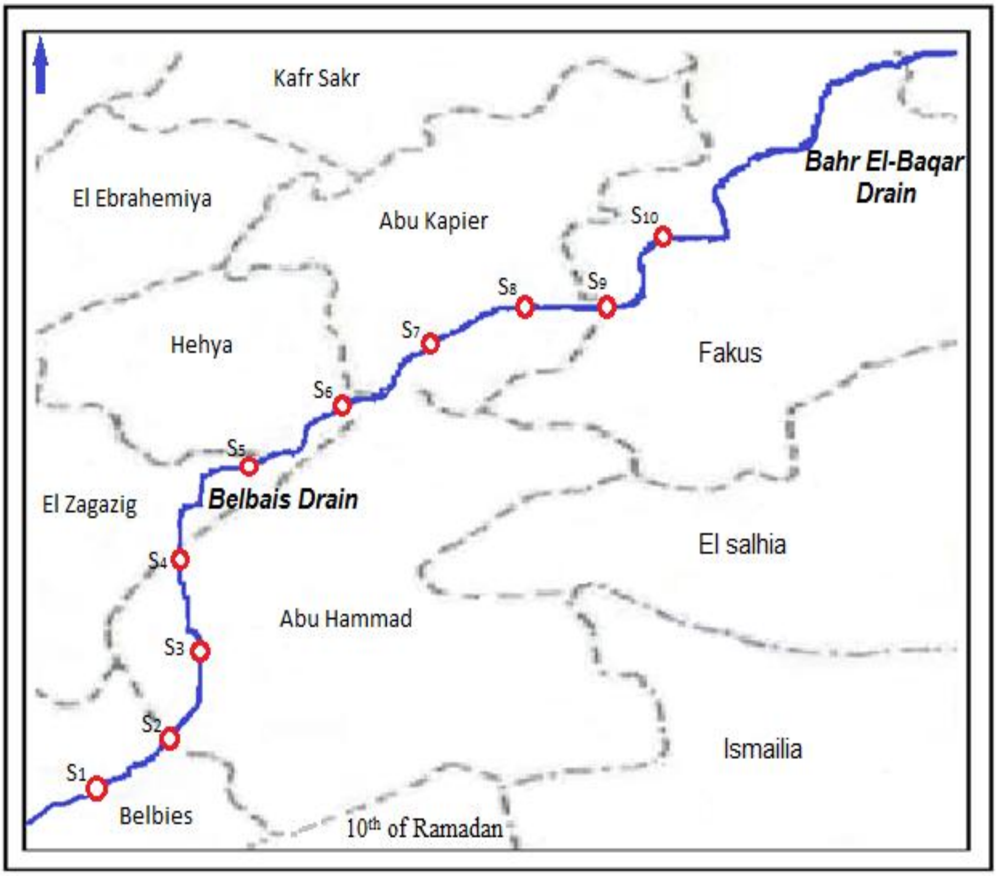

Fig 1. Location description and site sampling

3.2. Soil, water and plant preparation and characteristics

Water samples were analyzed for their chemical properties using methods cited by **Chapman and Pratt, (1978)** and **Page *et al.* (1982)** and the results are presented in Table 1

Table 1. Chemical composition of wastewater of Belbais drain

Code No.	pH	EC dSm^{-1}	Cation ($mmol_c\ L^{-1}$)				Anion ($mmol_c\ L^{-1}$)				B $mg\ L^{-1}$
			Na^+	Ca^{2+}	Mg^{2+}	K^+	HCO_3^-	CO_3^{2-}	Cl^-	SO_4^{2-}	
L1	7.4	1.7	7.84	6.00	1.70	1.46	2.40	0.0	9.14	5.46	1.70
L2	7.5	1.6	8.70	6.10	1.10	0.10	2.60	0.0	9.50	3.90	1.25
L3	7.3	1.7	7.90	6.20	1.80	1.10	2.50	0.0	10.50	4.00	1.45
L4	7.4	1.6	7.60	6.30	1.70	0.40	2.70	0.0	10.70	2.60	1.04
L5	7.2	1.7	8.50	6.60	1.60	0.30	2.80	0.0	10.80	3.40	1.93
L6	7.5	1.7	8.60	6.80	1.50	0.10	3.40	0.0	11.00	2.60	1.52
L7	7.4	1.8	9.74	6.06	1.10	1.10	2.90	0.0	10.90	4.20	0.96
L8	7.5	1.7	7.00	6.10	1.80	2.10	2.60	0.0	8.60	5.80	1.77
L9	7.3	1.7	8.20	5.70	1.90	1.20	3.00	0.0	10.10	3.90	0.89
L10	7.1	1.8	8.10	6.00	1.80	2.10	2.90	0.0	10.50	4.60	1.12

L1 to L10: are locations 1 to 10 investigated along the Belbais drain;
EC: electrical conductivity

Soil samples were collected from the surface layer (0-30 cm depth). The representative surface soil samples were collected in polyethelene bags using ultra clean spades with no possible contamination. Soil samples were air dried, crushed and sieved to pass through a 2 mm sieve then thoroughly mixed to be homogeneous for the different soil analyses. Chemical and physical properties of the investigated locations were determined according to **Klute (1986)** and **Page *et al.* (1982)** and the results are presented in Table 2.

Table 2. Chemical and physical properties of the investigated locations

Site*	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10
EC**(dS m^{-1})	1.4	1.9	3.8	2.0	1.6	1.8	1.8	1.5	2.2	2.3
pH***	7.3	7.3	7.2	7.2	7.4	7.3	7.2	7.4	7.2	7.4
$CaCO_3$ (g kg^{-1})	33.9	31.4	36.5	30.2	29.7	30.0	24.2	33.3	30.1	29.5
OM (g kg^{-1})	14.1	20.0	12.4	18.1	13.9	11.8	13.2	20.4	15.6	16.4
Particle size distribution and soil texture****										
Sand, %	40.1	36.3	31.2	27.5	28.4	29.5	28.9	26.8	29.1	27.0
Silt, %	40.2	43.6	49.1	48.5	49.6	50.3	52.3	50.8	55.1	51.3
Clay, %	19.7	20.1	19.7	24.0	22.0	20.2	18.8	22.4	15.8	21.7
Texture	CL	SiCL	SiCL	SiCL	SiCL	SiCL	SiCL	SiCL	SiCL	SiCL

* See footnotes of Table 1 - **EC of soil paste extract - ***pH in 1:2.5 w:v (soil:water) suspension

****According to international soil texture triangle CL: Clay Loam SiCL: Silty Clay Loam

Plant samples were washed with tap water, then deionized water, separated into straw and grain, oven dried at 70^0C for 48 h and then grinded to pass through a 5mm sieve.

3.3. Water, soil and plant analyses

Soil samples were acid digested in a block digester using a mixture of H_2SO_4 (conc.) and H_2O_2 (conc.) according to **Buondeonno *et al.*, (1995)**. Plant samples were acid digested according to **Peterburgski**, **(1968)**. N-contents were determined in the digests of soil and plant as well as in the wastewater samples using Kjeldahl method **(Page *et al.*, 1982)**. Phosphorus was determined in the wastewater, digests of soil and plant according to the phospho-molybdate-vanadate method **(Gupta *et al*., 1993)** and measured spectro-photometrically. Boron and Arsenic were measured in the wastewater, digests of soil and plant using the Inductively Coupled Plasma-Emission Spectrometry (ICP-MS).

3.4. Methods of analysis

3.4.1. Water analysis

- Electrical conductivity (EC) and pH immediately at the sampling points using pH/conductivity meter, model pH con 10 series, Cole Parmer **(Jackson, 1967)**.
- Soluble cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) and anions (CO_3^{2-}, HCO_3^{-}, Cl^{-}) in water samples were analyzed according to standard methods described by (**Page *et al.*, 1982**) as follow:

- Calcium and magnesium by titration against sodium versinate (0.01 N Na_2 EDTA) using murexide and EBT as indicators, respectively **(Jackson, 1967)**.
- Sodium and potassium were determined photo metrically using the flame photometer **(Jackson, 1967)**.
- Carbonate (CO_3^{2-}) and bicarbonate (HCO_3^{-}) were determined by titration against a standard 0.1 N HCl using phenolphthalein and methyl orange as an indicators, respectively **(Jackson, 1967)**.
- Soluble sulfate was calculated as a difference between summation of total determined cations and determined anions.
- Arsenic and Boron contents in the water samples were determined using ICP-MS.

3.4.2. Soil analysis

- Particle size distribution was carried out using the pipette method as outlined by **(Klute, 1986)** in which sodium hexameta phosphate is used as a dispersing agent.
- Calcium carbonate content was determined volumetrically using Collins calcimeter,**(Jackson, 1973).**
- Organic matter content was determined using the Walkley and Black method, as described by **(Jackson, 1967).**

- Soil pH was determined in 1:2.5 soil: water suspension using a Beckman glass electrode pH-meter **(Page *et al.*, 1982)**.

- Electrical conductivity (EC) in saturated soil paste extract was determined as described by **(Jackson, 1967)**.

- Soluble cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) and anions (CO_3^{2-}, HCO_3^{-}, Cl^{-}) in soil saturated paste extract were determined as mentioned before.

<u>Available nutrients:</u>

- Available N was extracted by using KCl according to method of **(Carter and Gregorich, 2008)** and was measured using the conventional method of Kjeldahl as described by **Bremner and Mulvany, (1982)**.

- Available P was extracted with 0.5 M ($NaHCO_3$) adjusted at pH of 8.5 and was determined at a wavelength 660 nm by spectrophotometer as described by **Olsen and Sommers (1982).**

- Available elements (As and B) were extracted by 5×10^{-3} DTPA according to **(Norvell, 1984)**. The Instrumental Neutron Activation Analysis (INAA) technique was used to measure the concentration of As in the soils as described by **Hamzah *et al.*, (2013)**.

<u>Total nutrients:</u>

- Total nitrogen content in soil samples was determined using the regular Kjeldahl method as described by **(Page *et al*., 1982)**.

- Total Phosphorus was determined in the digest of soil according to the phospho-molybdate-vanadate method **(Gupta *et al*., 1993)** and measured spectro-photometrically.

- Total boron in the soil was determined by the curcmin-acitic acid method according to **Yamada and Hattori, (1986)**.

- Total content of arsenic (As) of the studied soils was determined in the digested soil samples using the Inductively Coupled Plasma-Emission Spectrometry (ICP-MS) after being digested by H2SO4-H2O2 acid mixtures according to **Buondeonno *et al*., (1995).**

3.4.3. Data analysis

Statistical analysis is performed to find out the relationships between element (N, P, B, As) contents in soils and plant, including the corresponding content in irrigation water (wastewater of Belbais drain) according to **Snedecor and Cochran, (1982)**. Analysis of variance was conducted using SPSS version 18.

4. RESULTS AND DISCUSSION

4.1. Evaluating the suitability of wastewater of Belbais for irrigation purposes

4.1.1. Salinity and sodicity evaluation of the wastewater of Belbais drain

Salts in soil or water reduce water availability to the crops to an extent that affects plant yield. The infiltration rate generally increases with increasing salinity and decreases with either decreasing salinity or increasing sodium content relative to calcium and magnesium (the sodium adsorption ratio, SAR). Therefore, salinity and SAR of irrigation water must be considered together for a proper evaluation of an ultimate effect on soil water infiltration rate. The **U.S.D.A., (1954)** recommended that both RSC and SAR can be used to evaluate sodicity hazard, if irrigation water has appreciable bicarbonate content, calcium and magnesium carbonate will precipitate when the concentration of the soil solution is increased through evapo-transpiration.

Figure 2 represent that the class of water was C3-S1 according to **Richards, (1954)**. Thus, special precautions are required when using such water for irrigation purposes such as adequate drainage system. Also, good tolerant plants are suggested for growing in soils irrigated with such wastewater. **Bhumbla and Abrol, (1972)** recommended using such water (C3-S1) for growing tolerant and semi tolerant crops in soils containing clay content between 20 to 30% without showing salt stress on the grown plants. Moreover, there was no restriction when using such water for irrigation on soil infiltration rate according to the guidelines of **FAO, (1985)**. However, there is a slight to moderate specific Na-toxicity when using such water for furrow irrigation. The magnesium ratio (Mg ratio) is taken as a measure for magnesium hazards as stated in **FAO/ UNESCO (1973)**, the magnesium ratio did not exceed the 50% ratio in all the investigated sites; neither did the RSC parameter (all values were negative) (Table 3). This probably indicates that the used water has no Mg or alkalinity hazards.

Table 3. Salinity and sodicity evaluation of the wastewater of Belbais drain

Site*	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10
EC*dSm^{-1}	1.7	1.6	1.7	1.6	1.7	1.7	1.8	1.7	1.7	1.8
SAR	2.83	3.24	2.80	2.69	2.97	2.98	3.64	2.49	2.95	2.90
Mg ratio	22.07	15.27	22.50	21.25	19.51	18.07	15.36	22.78	25.00	23.07
RSC	-5.30	-4.60	-5.50	-5.30	-5.40	-4.90	-4.26	-5.30	-4.60	-4.90

* See footnotes of Table 1,
SAR: Sodium Adsorption Ratio,
RSC: Residual Sodium Carbonate

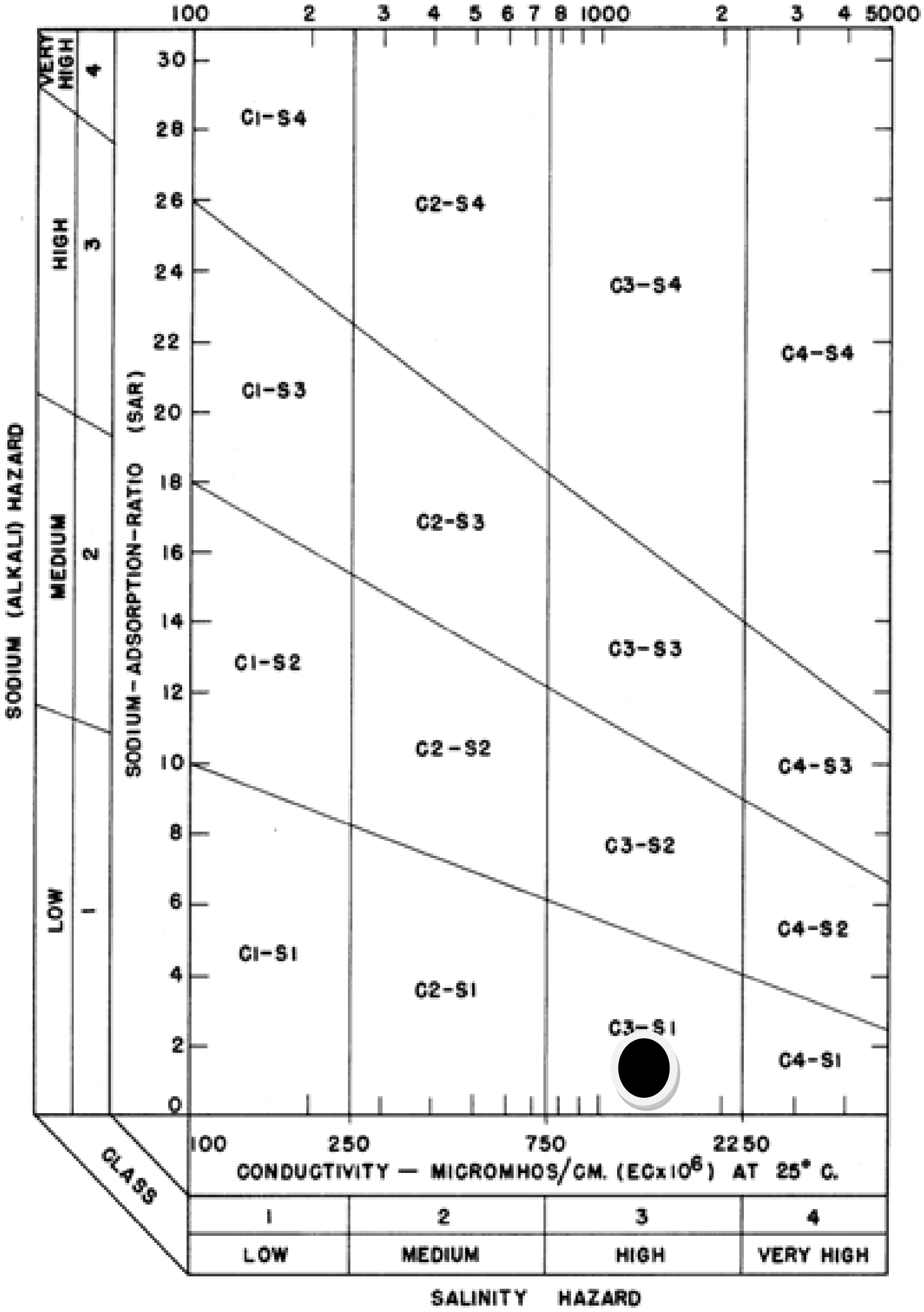

Fig. 2. The classes of the wastewater of Belbais drain

4.1.2. Elements in the wastewater of Belbais drain

Analysis of variance shows that wastewaters collected from the studied locations varied significantly in their contents of NO_3-N, P, B and As (Table 4). It is necessary to follow up the changes that occurred in concentrations of the investigated elements along the drain to determine whether these concentrations followed a definite distribution pattern by either increasing or decreasing along the drain. This might explain the behavior of these elements in soils of the nearby farms. A distribution pattern of increase in concentrations along the drain probably indicates that the wastewater, which already contains high concentrations of the studied elements, would receive further quantities of these elements from the nearby farms through leaching, while a distribution pattern of a decrease in concentrations of these elements probably indicates that these elements accumulate at high concentrations in soil sediments of the nearby arable lands.

Significant variations in concentrations of NO_3-N, P, B and As were detected in the wastewater of Belbais drain from location 1 to 10 (Figures 3 and 4). In spite of that, there were no concentration trends or distribution patterns detected for the four investigated elements along the drain i.e. concentrations of these elements did not follow either an increase pattern or a decrease one along the drain. Such a result supports an assumption that the agricultural practices in the arable lands surrounding the drain may have relatively higher impacts on accumulation of elements in soils and within the grown plants than their concentrations in the wastewater.

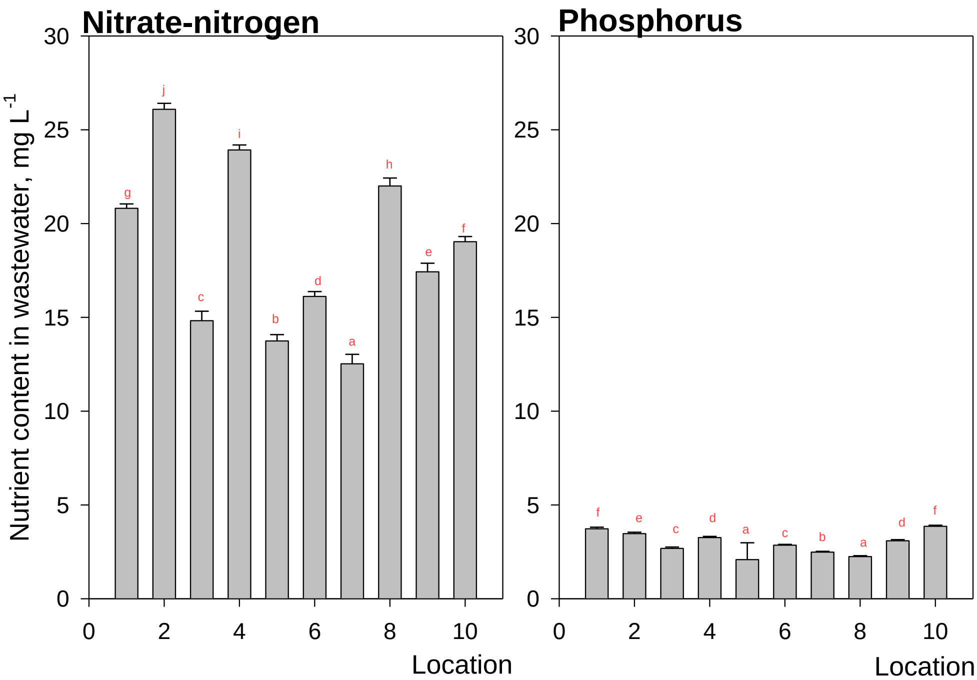

Fig 3. Nitrate-nitrogen and P - concentrations in the wastewater along the drain of Belbais

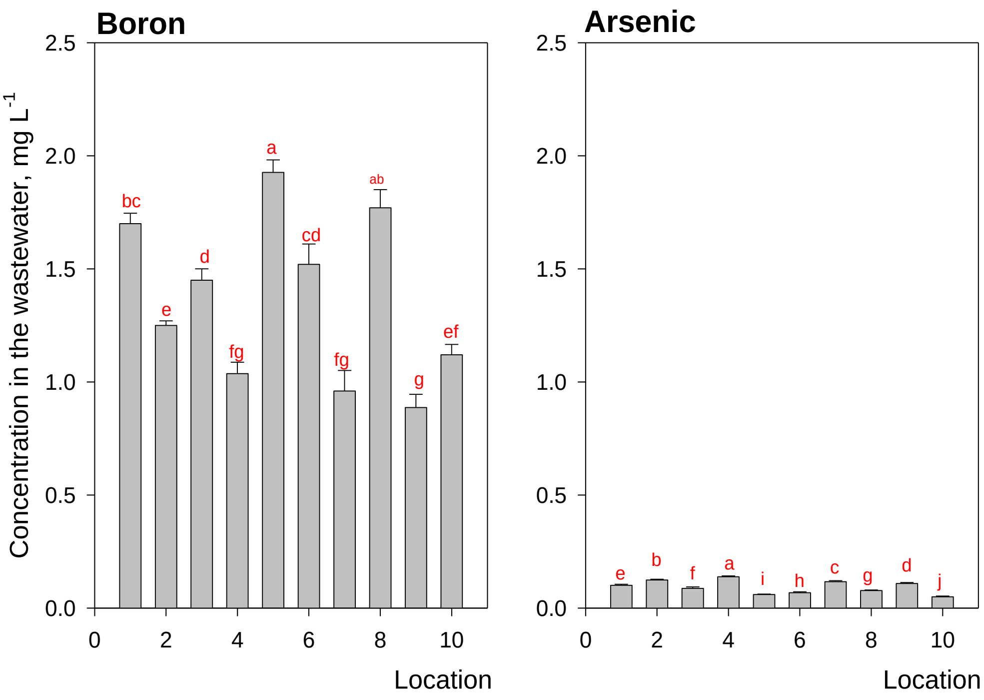

Fig 4. Boron and arsenic concentrations in the wastewater along the drain of Belbais

Table 4. Analysis of variance for the concentrations of NO_3-N, P, B and As in the wastewater collected from the different locations along the drain

Source	Nitrogen					Phosphorus				
	DF	SS	MS	F	P	DF	SS	MS	F	P
Location	9	550.22	61.14	440.76	<0.001	9	10.065	1.12	262.72	<0.001
Error	20	2.77	0.139			20	0.0855	0.004		
Total	29	443.00				29	10.15			
	Boron					**Arsenic**				
Location	9	3.59	0.40	102.61	<0.001	9	0.23	0.003	162.99	<0.001
Error	20	0.078	0.004			20	0.0003	0.00001		
Total	29	3.67				29	0.024			

4.1.2.1. Nitrogen and phosphorus in the wastewater of Belbais drain

Fig. 3. showed that the highest concentration of NO_3-N in wastewater was detected at location 2; whereas, the highest concentrations of P were found at locations 1 and 10 , and P decreased in between these locations. The NO_3-N in wastewater exceeded the safe range of 0-10 mg L^{-1} in irrigation water with a slight to moderate degree of restriction on use (5-30 mgL^{-1}) according to **FAO, (1994)**. P-content in the wastewater exceeded its safe range in irrigation water (0-2 mgL^{-1}). Although, managing such wastewater may have beneficial effects on plant because of its high contents of N and P, excessive use of it with unmanaged irrigation system would cause adverse effects on the ecosystem. Efficient management of irrigation water is vital for avoiding contamination of surface water with nitrogen **(Diez *et al*., 2000; Spalding *et al*., 2001; Cavero *et al*., 2003 and Zotarelli *et al*., 2009)**.

4.1.2.2. Boron and arsenic in the wastewater of Belbais drain

Fig. 4. showed that the highest concentration of B in wastewater was detected around location 5; whereas, the least concentration was found at location 9. Boron concentrations in wastewater had a slight to moderate degree of restriction on use (0.7-3 mg L^{-1}) according to **FAO, (1994)**. On the other hand, the highest concentrations of As in wastewater of Belbais drain were in location 4. Although the concentrations of As in wastewater seemed relatively low, they exceeded, in many locations, the permissible level of 0.1 mg As L^{-1} in irrigation water suggested by **FAO, (1992)** and **Rahaman *et al*., (2013)**. Therefore, using such water for irrigation purposes might possess a serious threat to animals and individuals feeding on plants grown in these areas.

4.2. Characterization of the studied soils.

4.2.1. Chemical and physical properties of the soil used in the study

The soils used in the study represent those adjacent to Belbais drain, irrigated complementary with wastewater of such drain and cultivated with wheat crop. Recently, these soils are classified according to (**Taxonomy, 2014**) and from the pedological point of view as ***Entisols***, ***Torripsamments*****.** The properties of the studied soils are present in Table 5.

Soil salinity values (EC_e) ranged between 1.4 and 3.8 dSm^{-1} indicated non-saline conditions for all sites under investigation. No specific trend of salinity could be observed along the studied sites.

Soil reaction (pH value) of these soils ranges from 7.2 to 7.4. The obtained soil pH values indicate a neutral effect on such values.

$CaCO_3$ content is considerable low, being in the range of 24.2-36.5 gkg^{-1}. The lowest content is found in the top soil surface layer of site No. 7 whereas; the highest content is that of the top surface layer of site No. 3. The soils are therefore, non-calcareous and this is mainly rendered to the nature of sediments from which these soils are derived.

Table 5. Chemical and physical properties of the studied soils (0-30 cm. depth).

Property	**Site***									
	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10
EC(dS m^{-1}) *	1.4	1.9	3.8	2.0	1.7	1.8	1.8	1.5	2.2	2.3
pH*	7.3	7.3	7.2	7.2	7.4	7.3	7.2	7.4	7.2	7.4
$CaCO_3$ (g kg^{-1})	33.9	31.4	36.5	30.2	29.7	30.0	24.2	33.3	30.1	29.5
OM (g kg^{-1})	14.1	20.0	12.4	18.1	13.9	11.8	13.2	20.4	15.6	16.4
Soluble cations ($mmol_c l^{-1}$)										
Ca^{2+}	6.8	7.9	14.1	8.1	7.1	6.7	7.0	6.9	9.3	9.4
Mg^{2+}	2.1	3.2	6.1	4.3	3.1	3.8	3.7	2.2	4.4	4.5
Na^{+}	4.2	7.6	12.1	6.8	6.5	5.6	5.8	4.4	8.2	8.2
K^{+}	0.9	0.3	5.7	0.8	0.3	1.9	1.5	1.5	0.1	0.9
Soluble anions ($mmol_c l^{-1}$)										
CO_3^{2-}	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HCO_3^{-}	2.4	4.4	5.1	3.4	3.9	3.2	3.5	2.3	3.0	2.4
Cl^{-}	6.5	8.9	18.9	9.3	8.1	8.6	8.2	7.4	14.9	14.1
SO_4^{2-}	5.1	5.7	14.0	7.3	5.0	6.2	6.3	5.3	4.1	6.5
Particle size distribution and soil texture*										
Sand %	40.1	36.3	31.2	27.5	28.4	29.5	28.9	26.8	29.1	27.0
Silt %	40.2	43.6	49.1	48.5	49.6	50.3	52.3	50.8	55.1	51.3
Clay %	19.7	20.1	19.7	24.0	22.0	20.2	18.8	22.4	15.8	21.7
Texture	CL	SiCL	SiCL	SiCL	SiCL	SiCL	SiCL	SiCL	SiCL	SiCL

*See footnotes of Tables 1 and 2

Organic matter content of these soils is very low, not exceeding 20.4 gkg^{-1}. This is expected due to less manuring and high rate of organic matter decomposition under the prevailed semi-arid climatic conditions. Organic matter content ranged from 11.8 to 20.4 gkg^{-1}, the lowest content was confined to the top layer of site No. 6 while, the highest content was found in the top surface of site No. 8.

The cationic composition of the soil saturation extract followed one distinct pattern i.e. $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+}$. It is also noticed that despite the predominance order of cations distribution, the concentration of each cation in soil varied from one site to another. The anionic composition of the soil saturation extract is characterized by the dominance of Cl^- followed by SO_4^{2-} and HCO_3^- while CO_3^{2-} is entirely absent. It is also clear that the order of abundance is unique regardless of variable concentration of anions from one site to another. Ionic composition (Combination of anionic and cationic composition) may predict that the dominant salts in the investigated soil sites are $CaCl_2$, NaCl or Na_2SO_4.

Texture of soil is clay loam to silt clay loam according to international soil texture triangle. Regarding the fine earth, it is quite evident that the soil fractions are dominated with silt, sand while the clay fraction is the least abundant. The silt fraction constitutes 40.2 to 55.1%, the sand fraction constitutes 26.8 to 40.1 % while the clay fraction forms 15.8 to 24.0 %.

4.2.2. Elements in the studied soil

Data presented in Table 6 show total and available concentrations of N, P, B and As in the studied soils. Analysis of variance revealed that the total and available contents of the investigated elements i.e. NO_3-N, P, B and

As changed significantly among the different locations along the Belbais drain (Tables 7 and 8).

4.2.2.1. Nitrogen and phosphorus in the studied soil

Total and available contents of nitrate and phosphorus varied significantly among soils at different locations along the Belbais drain (Figs. 5 and 6). The highest concentration of N was detected at location 2, whereas the highest concentration of P was found at location 10. Concentrations of these nutrients did not follow any distribution pattern along the drain of Belbais.

4.2.2.2. Boron and arsenic in the studied soil

Although, there were slight variations in concentrations of the investigated elements among the different locations; however, such differences were significant (Fig.5). The highest concentrations of B in soil were found at the fifth location; whereas, the highest concentrations of As were found at the second location. Generally, concentrations of As did not exceed the permissible level of 10 mg kg^{-1} reported by **(Basta *et al*., 2002).** Neither did soil-As exceed the thresholds of 5 mg kg^{-1} in Finnish soils or 12 mg kg^{-1} in Canadian soils reported by **(Teaf *et al*., 2010)**.

Table 6. Total and available concentrations of N, P, B and As in the studied soil

Location	Nitrogen, mg kg^{-1}		Phosphorus, mg kg^{-1}		Boron, mg kg^{-1}		Arsenic, mg kg^{-1}	
	Total	Available	Total	Available	Total	Available	Total	Available
1	120.7	70.47	15.28	7.72	12.63	3.38	7.14	0.81
2	139.8	77.56	16.49	7.56	10.8	2.79	8.70	0.95
3	107.9	62.43	13.66	6.28	11.47	2.95	6.67	0.75
4	135.6	75.57	15.87	7.26	9.4	2.44	9.18	0.99
5	103.5	60.16	11.42	5.43	13.98	3.71	5.63	0.673
6	112.1	64.31	14.39	6.66	12.16	3.17	6.13	0.68
7	99.7	58.4	12.98	6.03	8.65	2.27	8.09	0.90
8	129.1	73.05	12.19	5.76	13.27	3.62	6.61	0.71
9	116.3	66.38	15.08	6.93	7.91	2.13	7.60	0.85
10	121.2	68.54	16.89	7.96	10.12	2.61	5.13	0.63

Table 7. Analysis of variance for the concentrations of total N, P, B and As in soil irrigated with the wastewater of Belbais drain

Source	**Nitrogen-Nitrate**					**Phosphorus**				
	DF	SS	MS	F	P	DF	SS	MS	F	P
Location	9	4821.33	535.70	3.766	0.006	9	43.395	4.822	2.675	0.032
Error	20	2844.86	142.24			20	36.050	1.802		
Total	29	7666.19				29	79.445			
	Boron					**Arsenic**				
Location	9	110.06	12.23	9.742	<0.001	9	46.630	5.181	10.004	<0.001
Error	20	25.11	1.26			20	10.358	0.518		
Total	29	135.17				29	56.988			

Table 8. Analysis of variance for the concentrations of available N, P, B and As in soil irrigated with the wastewater of Belbais drain

Source	Nitrogen-Nitrate					Phosphorus				
	DF	SS	MS	F	P	DF	SS	MS	F	P
Location	9	1141.39	126.82	366.24	<0.001	9	20.50	2.28	351.43	<0.001
Error	20	6.93	0.35			20	0.13	0.007		
Total	29	1148.32				29	20.63			
	Boron					**Arsenic**				
Location	9	8.32	0.93	154.56	<0.001	9	0.41	0.05	394.04	<0.001
Error	20	0.12	0.006			20	0.002	0.0001		
Total	29	8.44				29	0.41			

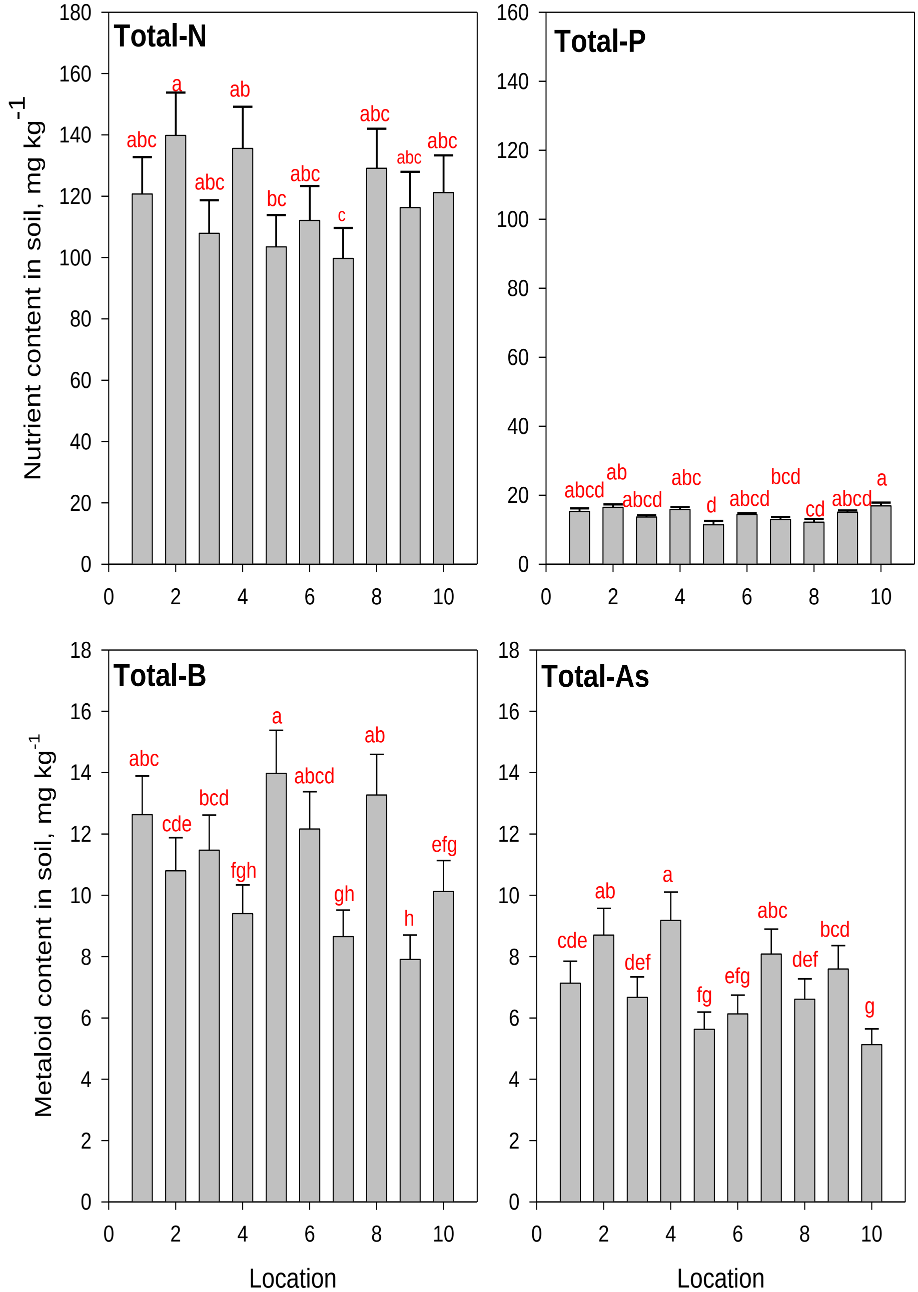

Fig. 5. Total contents of nitrate-nitrogen, phosphorus, boron and arsenic in soils nearby Belbais drain

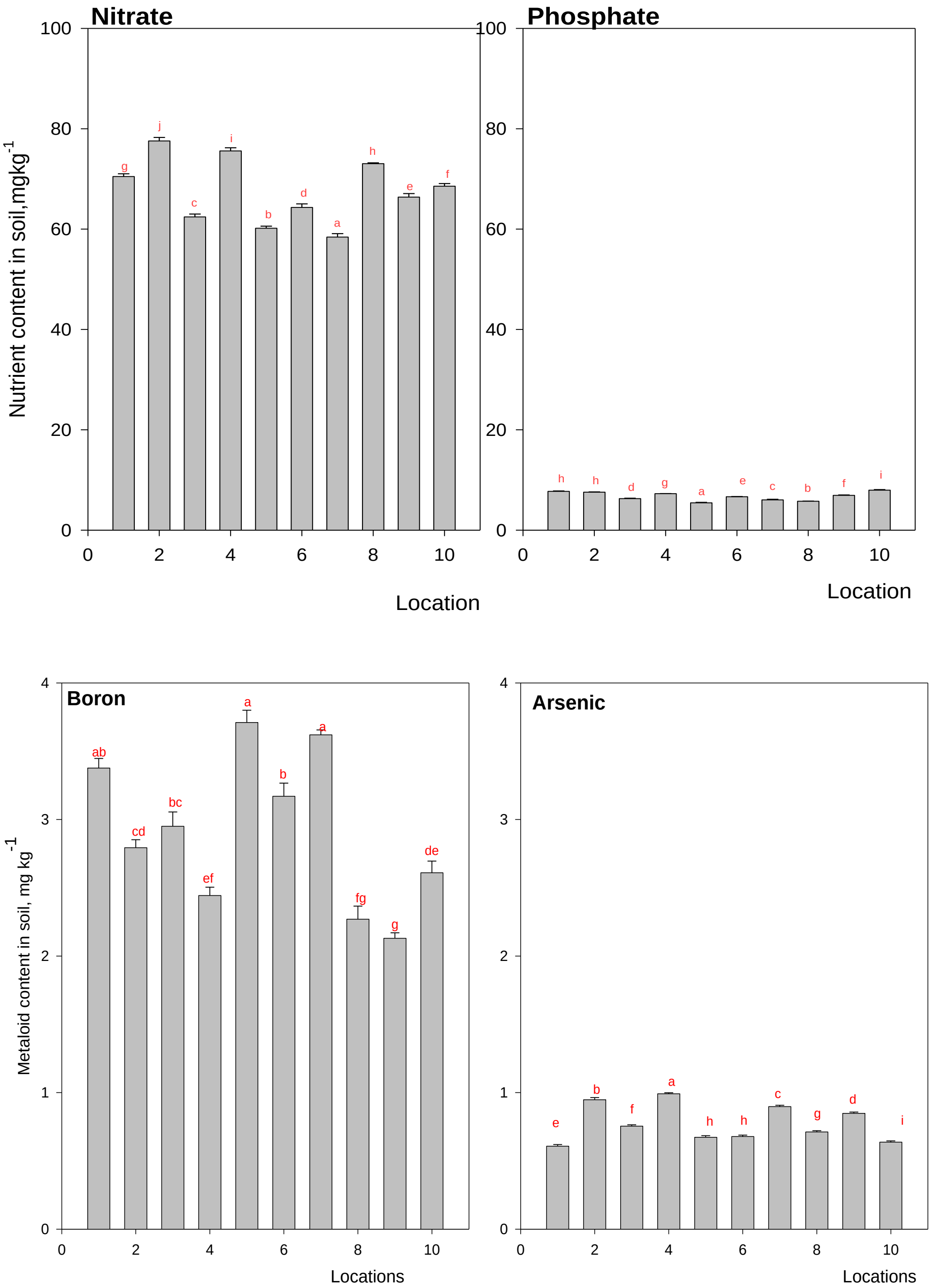

Fig. 6. Available contents of nitrate-nitrogen, phosphorus, boron and arsenic in soils nearby Belbais drain

4.3. Elements in the aboveground tissues of the cultivated wheat plants

This part of study focuses on concentration of elements in the above ground tissues of wheat plants (shoot and grain) grown on the aforementioned soils. Concentrations of N, P, B and As in the above ground tissues of wheat plants are presented in Table 9.

Table 9. Concentrations of N, P, B and As in the above ground tissues of wheat plants

Location*	Nitrogen, mg kg^{-1}		Phosphorus, mg kg^{-1}		Boron, mg kg^{-1}		Arsenic, mg kg^{-1}	
	Shoot	Grain	Shoot	Grain	Shoot	Grain	Shoot	Grain
1	18.50	12.16	0.36	0.29	11.41	7.03	4.52	2.72
2	19.93	13.51	0.35	0.28	10.53	5.35	5.17	3.18
3	16.35	10.66	0.27	0.22	10.84	5.82	4.41	2.52
4	19.36	13.18	0.32	0.27	9.84	4.61	5.41	3.39
5	15.74	10.08	0.21	0.18	12.08	8.14	3.87	2.05
6	16.81	11.05	0.29	0.25	11.03	6.30	3.99	2.22
7	14.84	9.74	0.25	0.21	9.72	4.17	4.94	3.09
8	18.83	12.66	0.23	0.20	11.77	7.54	4.25	2.35
9	17.33	11.39	0.31	0.26	9.44	4.78	4.76	2.88
10	18.02	11.86	0.38	0.30	10.13	4.95	3.66	1.87

* See footnotes of Table 1.

Analysis of variance shows that N, P, B and As in shoots and grains of wheat plants varied significantly among the locations (Table 10).

Table 10. Analysis of variance for the concentrations of NO_3-N, P, B and As in wheat plants collected from different locations along Belbais drain

Source	Nitrogen					Phosphorus				
Shoot										
	DF	SS	MS	F	P	DF	SS	MS	F	P
Location	9	155.42	17.27	225.13	<0.001	9	0.09	0.0099	359.45	<0.001
Error	20	1.53	0.08			20	0.0006	0.0003		
Total	29	156.95				29	0.09			
Source	**Boron**					**Arsenic**				
Location	9	21.85	2.43	462.52	<0.001	9	8.97	0.996	130.42	<0.001
Error	20	0.11	0.005			20	0.15	0.008		
Total	29	21.96				29	9.12			
Grain										
Source	**Nitrogen**					**Phosphorus**				
Location	9	99.37	11.04	497.36	<0.001	9	0.046	0.005	221.98	<0.001
Error	20	0.44	0.02			20	0.0005	0.00002		
Total	29	99.82				29	0.046			
Source	**Boron**					**Arsenic**				
Location	9	48.58	5.40	560.15	<0.001	9	6.96	0.773	216.33	<0.001
Error	20	0.19	0.01			20	0.07	0.004		
Total	29	48.77				29	7.03			

4.3.1. Nitrogen and phosphorus in wheat plant

Concentrations of nitrogen and phosphorus varied significantly in shoot and grain of wheat plants collected from different locations (Fig. 7).

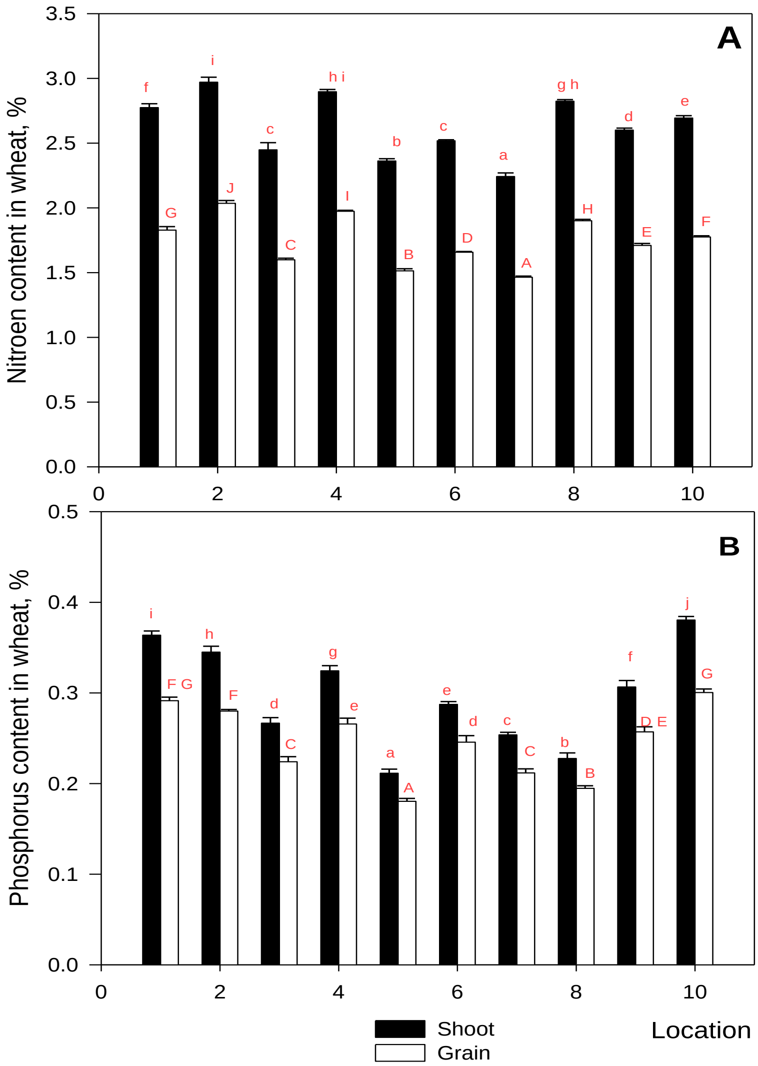

Fig. 7. Nitrogen and phosphorus in the aboveground wheat parts

The highest nitrogen contents in wheat shoot and grain were detected at location 2, whereas, the highest phosphorus contents in shoot and grain of wheat plants were detected at location 10. However, these concentrations were within the normal ranges of N and P in wheat shoot **(Korzeniowska, 2008)**.

4.3.2. Boron and arsenic in wheat plant

Concentrations of B and As varied significantly in shoot and grain of wheat plants collected from the locations; however such variations did not follow any distribution trend (Fig. 8). The highest concentrations of B in shoot and grain took place at location 5; whereas, the highest As in shoot and grain took place at location 4.

Symptoms of B toxicity could be observed on wheat shoot **(Grieve and Poss, 2000)** when B exceeds 44 mg kg^{-1} (**Furlani *et al.*, 2003**). The results obtained herein indicate that B-concentrations in wheat shoot were much lower than 44 mg kg^{-1}. Therefore, wheat plants did not suffer from B toxicity. On the other hand, As in grains exceeded the permissible level of 1mg kg^{-1} for food stuff **(Liu *et al.*, 2012)**. A dietary intake of food stuff highly contaminated with As would cause negative implications on human health **(Smith *et al.*, 2008)**. Thus, wheat grains collected from the area of study are not suitable for humans.

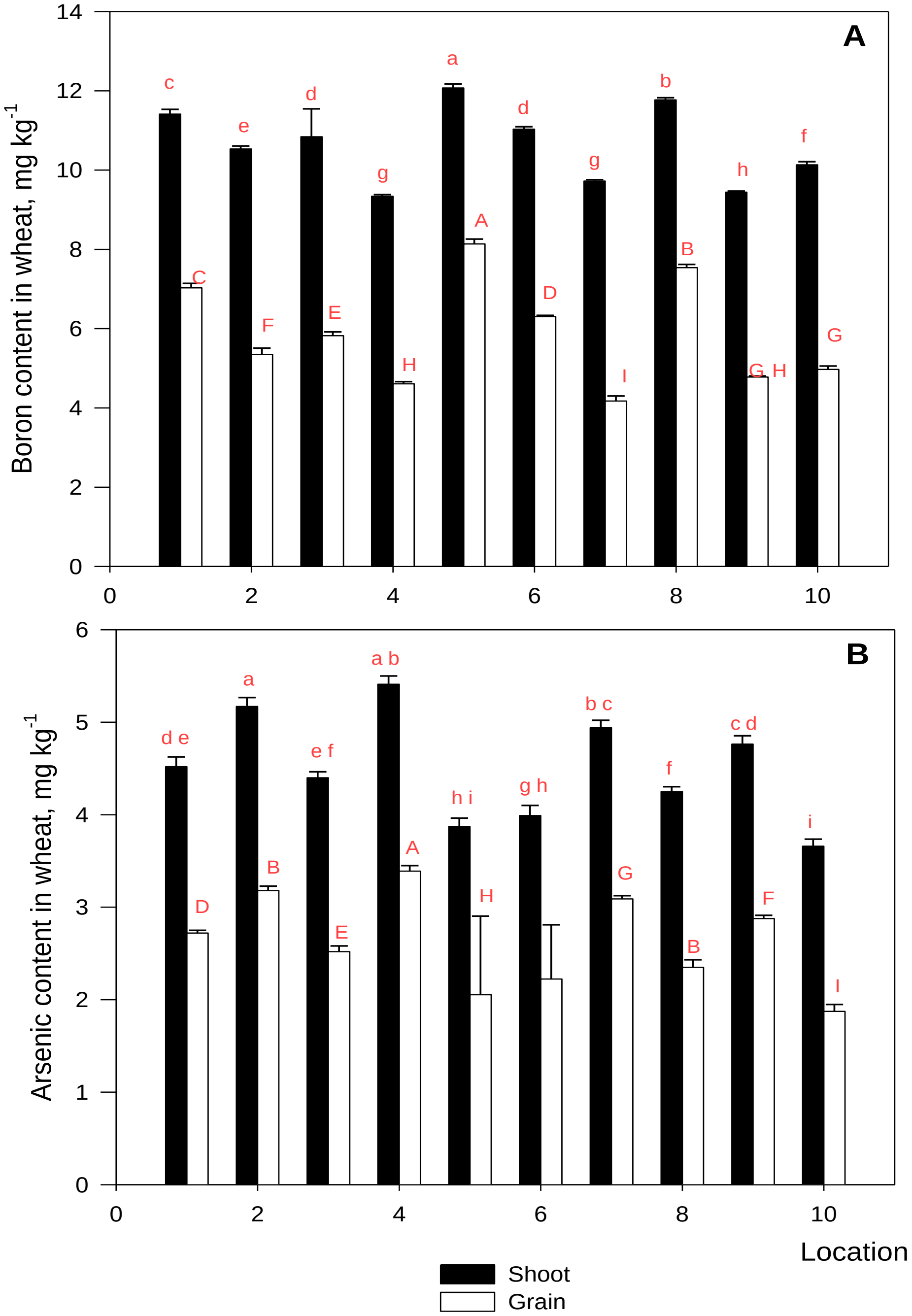

Fig. 8. Boron and arsenic contents in the aboveground wheat parts

The ratio between concentrations of the investigated elements in grains to the corresponding ones in shoots was calculated and the results are presented in Fig. 9. Elemental grain/shoot ratio varied between 0.5439 and 0.8299. This ratio therefore can be used as an indicator to illustrate the ease by which an element such as those studied therein can transfer from shoots to grains. Probably, values of more than 0.5 are indicators of relatively high translocations of the investigated elements from shoot to grain.

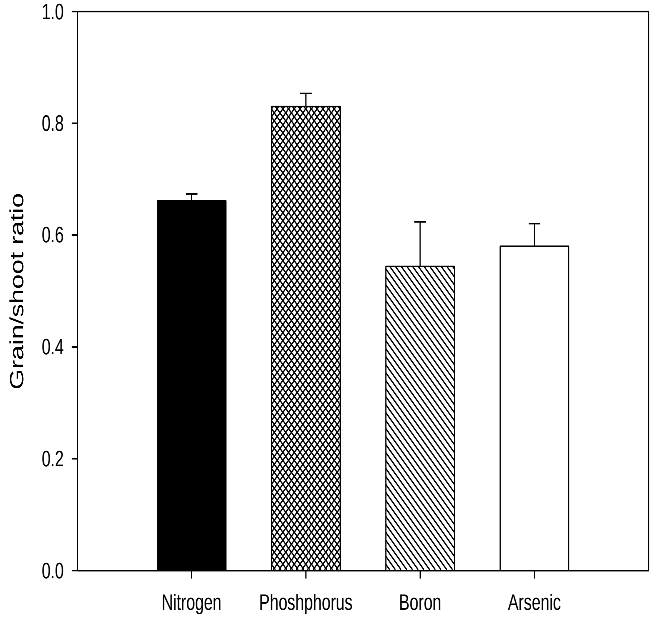

Fig. 9. Elemental grain/shoot ratio of absorbed elements in wheat plants grown in the arable lands irrigated with the wastewater of Belbais drain.

4.4. Soil-water-plant relationships

Table 11 reveals that N and P contents in shoot and grain of wheat significantly positively correlated with contents in each of the soil and water. Also, significant positive correlations occurred between N and P contents in water and their corresponding ones in soils. Likewise, As and B contents in shoot and grain significantly positively correlated with their corresponding contents in soil and water. Such a result indicates that accumulation of these elements in soil led to consequent increases in their contents in wheat shoots and grains and had further impacts on contaminating the wastewater coming from Cairo. Nitrate is expected to leach out of the soil at rates exceeding the crop requirements **(Di and Cameron, 2002; Ju *et al.*, 2006)**. The significant calculated correlations were fitted to a linear model to investigate the extent of using the wastewater of Belbais drain on the accumulation of the investigated elements in soil and wheat segments.

Table 11. Soil-water-plant correlations of N, P, B and As

	Nitrogen				Phosphorus			
	Water	Total content	Available content	Shoot	Water	Total content	Available content	Shoot
Total content	0.803**				0.662***			
Available content	0.992***	0.789**			0.986***	0.700***		
Shoot	0.983***	0.766**	0.983***		0.990***	0.681***	0.992***	
Grain	0.992***	0.789**	0.996***	0.987***	0.985***	0.665***	0.993***	0.986***
	Boron				**Arsenic**			
	Water	Total content	Available content	Shoot	Water	Total content	Available content	Shoot
Total content	0.872***				0.878***			
Available content	0.383*	0.332			0.978***	0.891***		
Shoot	0.985***	0.899***	0.377		0.981***	0.886***	0.980***	
Grain	0.969***	0.859***	0.290	0.972***	0.989***	0.892***	0.983***	0.983***

4.4.1. Nitrogen relationships within soil, water and the grown wheat plants

A positive significant linear relationship was detected between N-NO_3 in the wastewater of Belbais drain and the corresponding available concentrations in soil, beside of N contents in shoot and grain (Fig. 10).

Accumulation of nitrogen in shoot and grain of the grown wheat plants were significantly and linearly correlated with the available-content in soil (Fig. 15). On the other hand, total soil-N recorded insignificant linear effect on N-concentrations in wheat shoot and grains (Fig. 14).

4.4.2. Phosphate relationships within soil, water and the gown wheat plants

Significant positive regressions were calculated for the relationships between P-contents in the wastewater of Belbais drain and either of the available contents in soil and the corresponding concentrations in shoot and grain (Fig. 11). On the other hand, the regression relationship between P-content in wastewater and the total content in soil seemed to be insignificant. Phosphorus contents in both shoot and grain increased linearly with increasing the corresponding available contents in soil (Fig. 15) and not with the total contents in soil (Fig. 14).

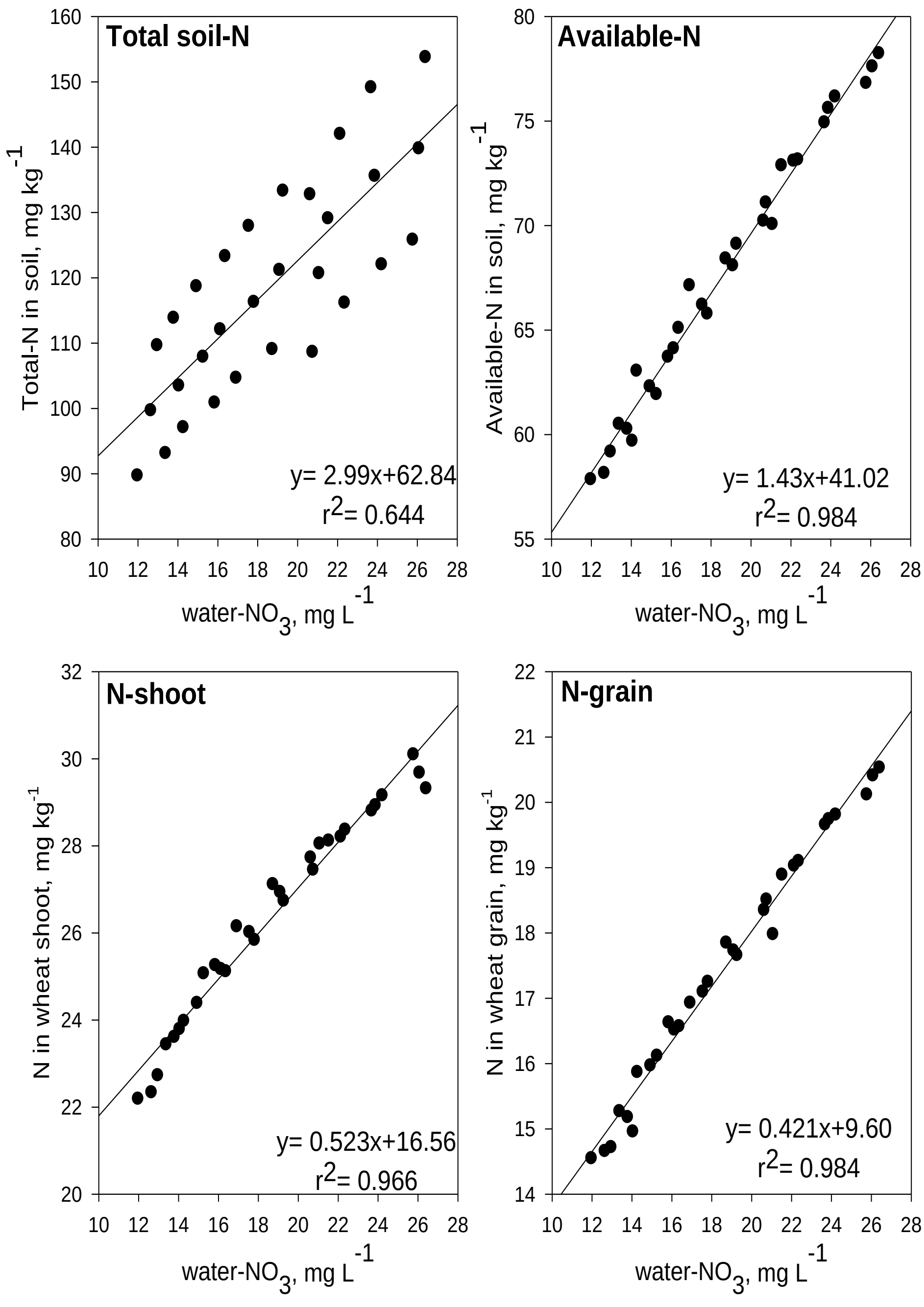

Fig. 10. Nitrogen content in soil and plant as affected by the corresponding concentrations in the wastewater of Belbais drain

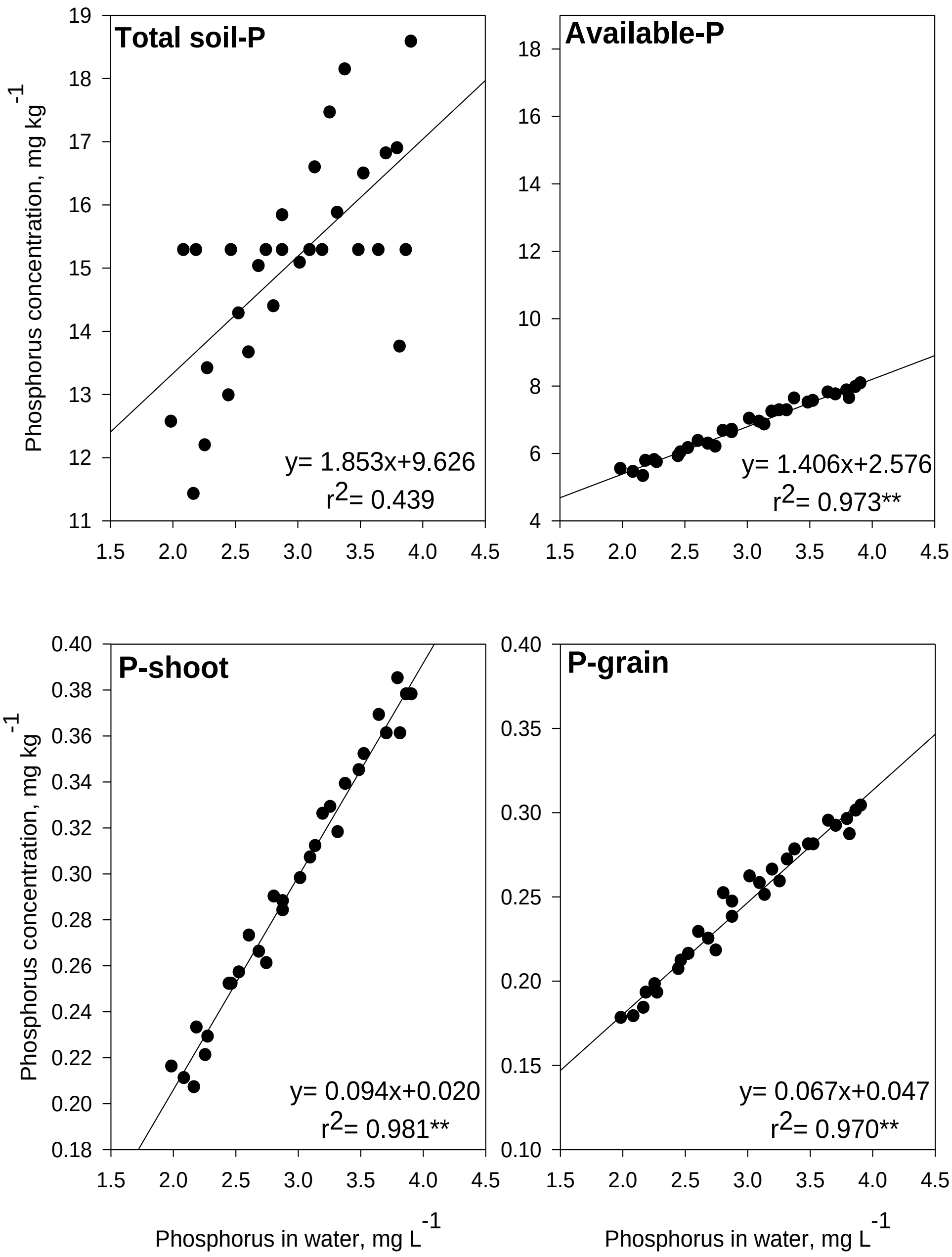

Fig. 11. Phosphorus content in soil and plant as affected by the corresponding concentrations in the wastewater of Belbais drain

4.4.3. Boron relationships within soil, water and the grown wheat plants

Significant regressions were found between B-concentrations in either shoot and grain with the corresponding contents in the wastewater of Belbais drain (Fig. 12). No significant regressions were found between B content in soil (total or available) and its content in the wastewater. On the other hand, B-content in shoot or grain was not linearly correlated with B content in soil (total or available) (Figs. 14 and15).

4.4.4. Arsenic relationships within soil, water and the grown wheat plants

Concentration of As in the wastewater of Belbais drain recorded significant linear relationships with the corresponding concentrations in wheat shoot and grain, as well as the available contents in soil (Fig.13). On the other hand, no significant regression was computed for the relation between total-As in soil and the corresponding contents in wastewater. Results also indicate that As-shoot and As-grain were positively and linearly affected by the available concentrations of As in soil (Fig. 15) and not by its total content in soil (Fig. 14).

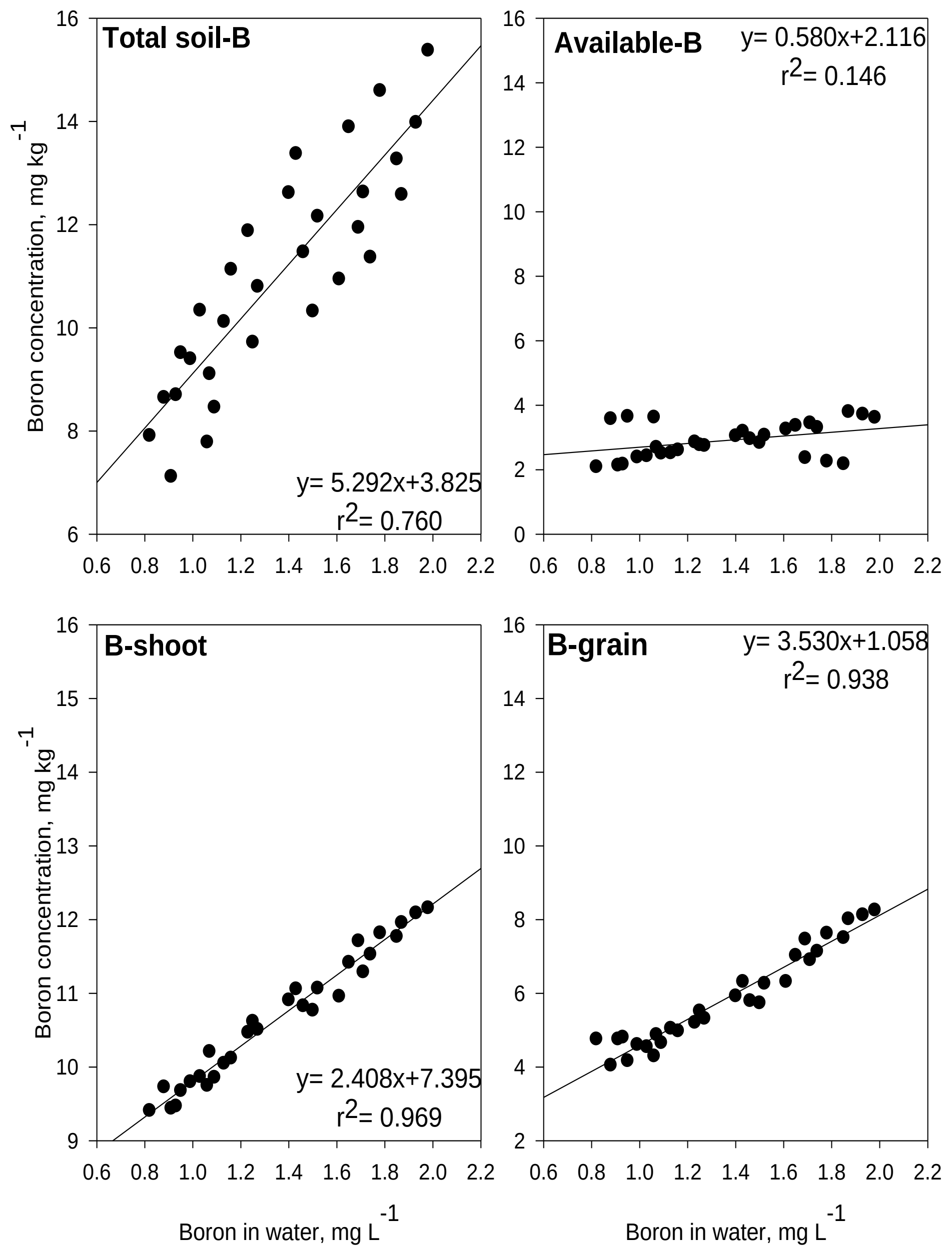

Fig. 12. Boron content in soil and plant as affected by the corresponding concentrations in the wastewater of Belbais drain

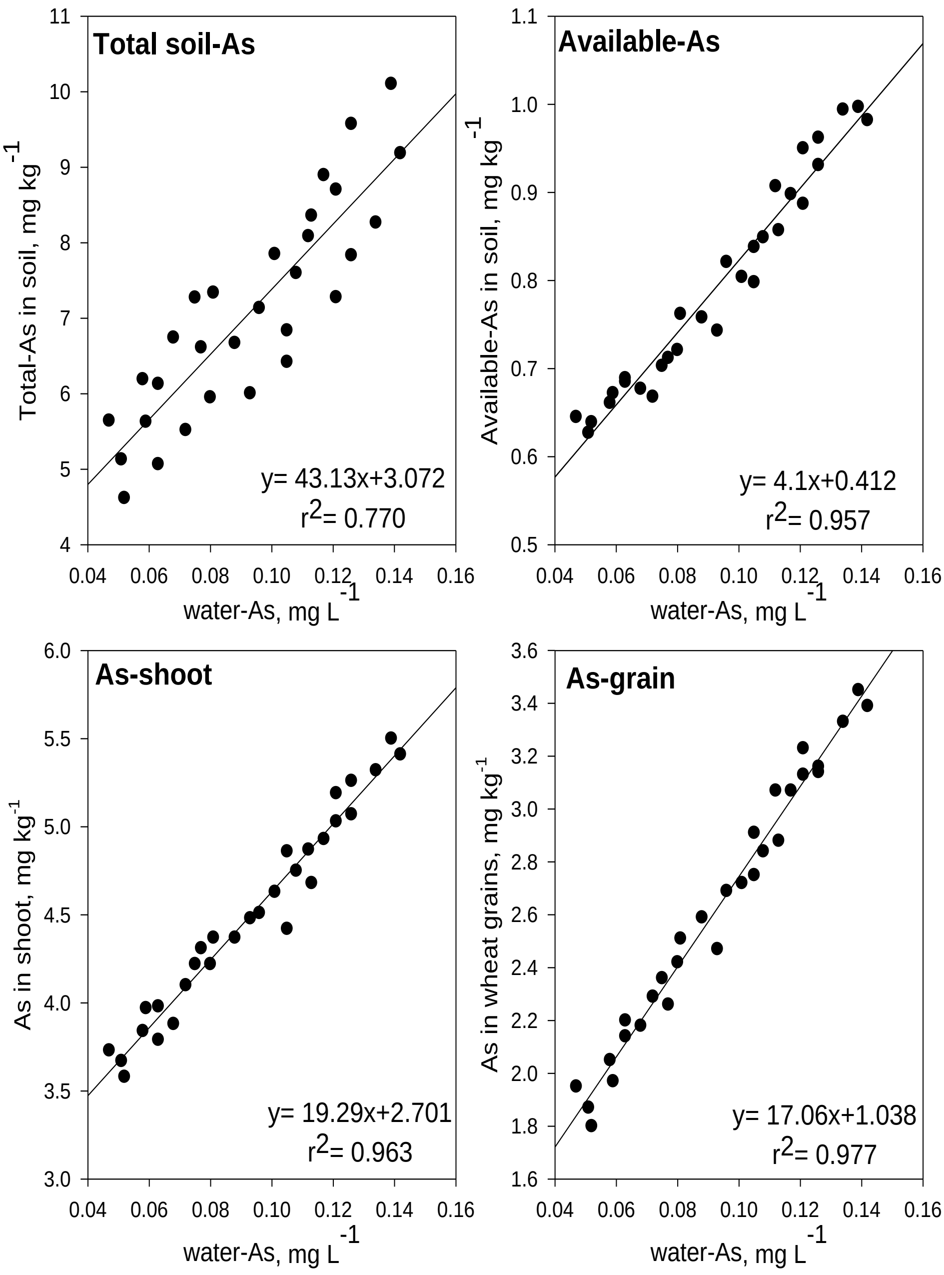

Fig. 13. Arsenic content in soil and plant as affected by the corresponding concentrations in the wastewater of Belbais drain

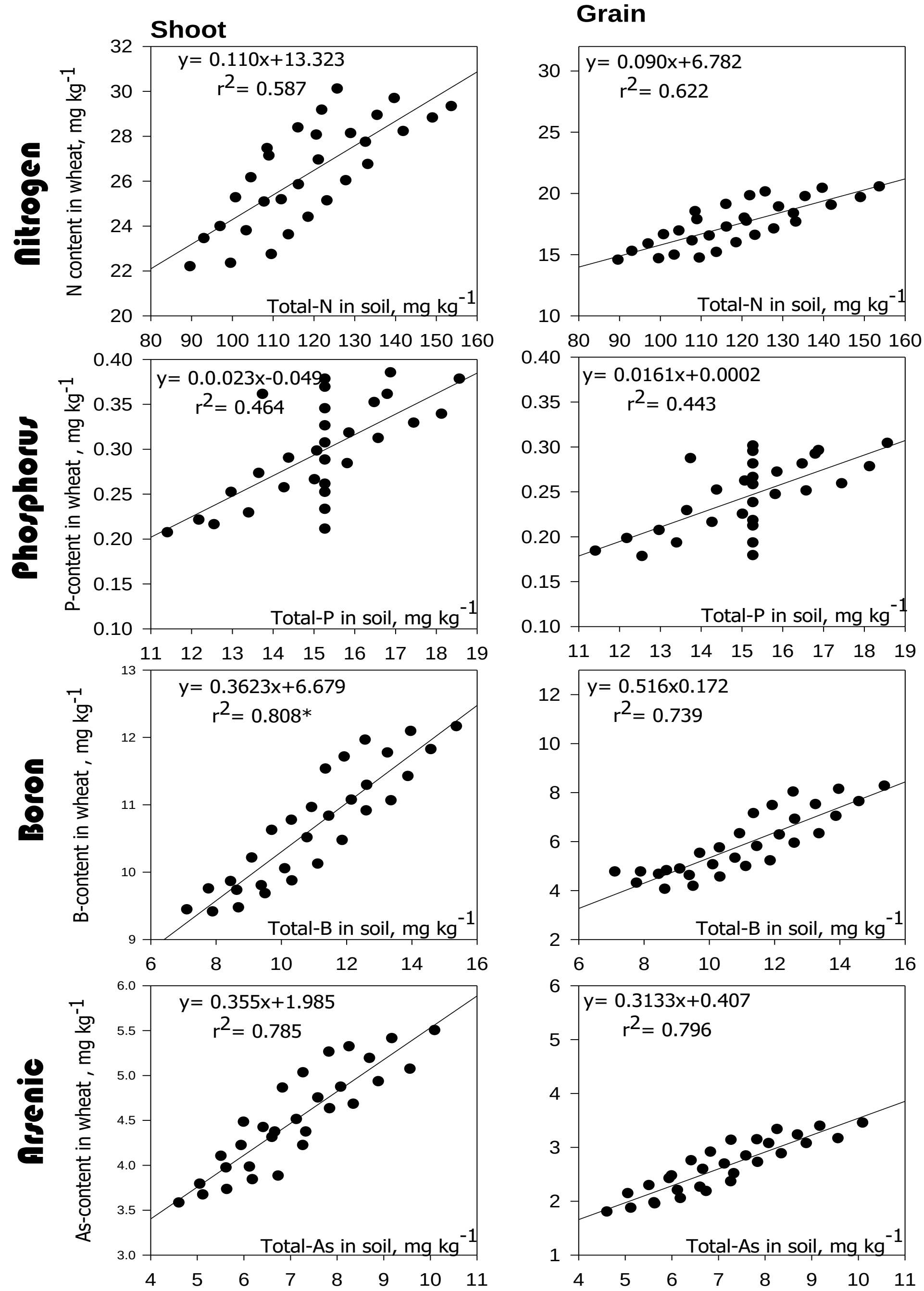

Fig. 14. Contents of elements in shoot and grain as affected by the corresponding total concentrations in soil

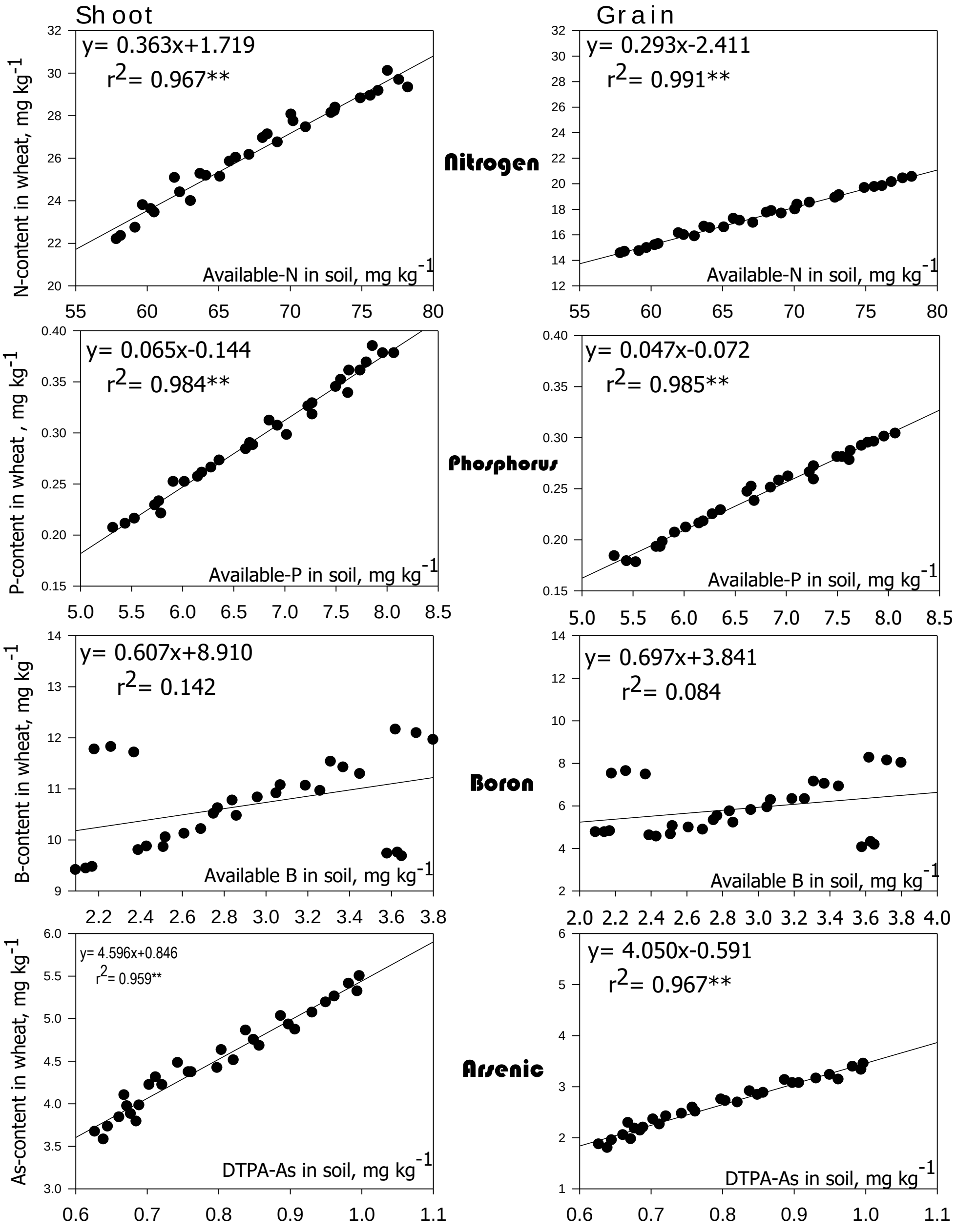

Fig. 15. Contents of elements in shoot and grain as affected by the corresponding available concentrations in soil

5. SUMMARY AND CONCLUSION

Water shortage is one of the important issues of the current and the coming centuries. Thus, many countries are forced towards using non-conventional water sources such as wastewaters. Egypt country is one of the countries located in the arid and semi-arid regions of the world. Scarcity of water in Egypt became more pronounced nowadays and is expected to be a problem of life and death, especially after the construction of the Ethiopian Renaissance Dam. Therefore, usage of alternative sources of water became of high importance. Using wastewater in complimentary irrigation became an obligation; however, compared with fresh waters, treated wastewaters usually contain higher contents of plant nutrients beside of some heavy or undesired metals and metaloids. Belbais drain is the main drain of Cairo. It carries lot quantities of waters that can be used for complimentary irrigation. To assess the implications of using wastewater of Belbais drain for complimentary irrigations of wheat, ten locations along the drain were selected for water sampling. Soil and wheat samples were also collected from the nearby farms at the aforementioned locations. There were no specific trends or distribution patterns detected for contents of each of NO_3-

N, P, B and As along the drain. NO_3-N in water had a slight to moderate degree of restriction on use. Also, P-content exceeded its normal range in irrigation water. In spite of that, contents of N and P in wheat were within the normal range in shoot and grain. Content of B in water had a slight to moderate degree of restriction on use, but plants did not exhibit B toxicity symptoms. Contents of As in water of many locations exceeded the permissible level of 0.1 mg As L^{-1}. Contents of As in soil (2.1 - 3.7 mg As kg^{-1}) did not exceed the permissible level of 10 mg kg^{-1}, but As in grains exceeded the permissible level of 1 mg kg^{-1} for food stuff. The calculated elemental grain/shoot ratio varied between 0.5439 and 0.8299. Individual practices of farmers on lands nearby Belbais drain are most certainly behind the increase in contents of the investigated elements in water of the drain. Efficient management of irrigation using wastewater of agricultural Drains in Egypt cannot be attained without increasing farmers' awareness of the negative aspects that may arise due to the unmanaged agricultural practices.

In conclusion, a hypothesis that individual practice of farmers on arable lands nearby Belbais drain is among the main causes for increasing levels of N, P, B and As in the wastewater of Belbais drain.

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الملخص العربي

أصبحت مشكلة نقص المياه احدى القضايا الهامة في الوقت الراهن والتي تواجه العديد من البلدان، مما دفعها إلى استخدام مصادر مياه غير تقليدية لزيادة كميات المياه المتاحة لديها مثل إعادة استخدام المياه العادمة، ومثل هذه المياه العادمة تحتوي حتى بعد معالجتها على العديد من المغذيات بمستويات تفوق تلك الموجودة في مياه الري التقليدية، وبالتالي يهدف هذا البحث إلى دراسة تداعيات استخدام المياه العادمة من مصرف بلبيس للري التكميلي لنباتات القمح المزروعة في اراضي منطقة شمال شرق الدلتا، حيث تم اختيار عشرة مواقع للدراسة على طول مصرف بلبيس، وتم جمع عينات من المياه العادمة عند تلك النقاط، كما تم جمع عينات تربة من الأراضي المجاورة لها بالإضافة إلى عينات من القمح النامي في تلك المناطق، وأوضحت النتائج عدم وجود أنماط محددة لتوزيع تركيز العناصر الأربعة موضع الدراسة على طول مصرف بلبيس، وبالنسبة لـ NO_3-N فدرجته في المياه العادمة تراوحت من خفيف إلى معتدل من حيث درجة القيد على استخدامها في الري، أيضا تجاوز محتوى الفوسفور بتلك المياه المدى المعتاد، وعلى الرغم من ذلك، كانت تركيزات N و P ضمن المستويات الطبيعية في الجزء الخضري والحبوب لنبات القمح، وقد كانت درجة البورون في المياه العادمة خفيفة إلى معتدلة من حيث درجة القيد على استخدامها؛ من جهة اخرى فإن النباتات النامية لم يظهر عليها أي اعراض سمية بالبورون، وأكدت النتائج على أن تركيزات الزرنيخ في العديد من المواقع على امتداد المصرف، قد تجاوز المستوى المسموح به لمياه الري (٠,١ ملجم لتر$^{-١}$). بينما لم يتجاوز تركيزه في التربة المستوى المسموح بها (١٠ ملجم كجم$^{-١}$)، ولكنه تعدى المستوى المسموح في الحبوب (١ملجم كجم$^{-١}$)، وقد تراوحت نسب العناصر المحسوبة في الحبوب إلى تلك في الجزء الخضري من ٠,٥٤٣٩ إلى ٠,٨٢٩٩ ، وبالتالي يمكن استنتاج أثر الممارسات الفردية للمزارعين في الأراضي القريبة من مصرف بلبيس قد تكون هي المصدر الرئيسي لزيادة مستويات العناصر موضوع الدراسة في مياه المصرف،

ومن ثم لا يمكن استخدام المياه العادمة لمصرف بلبيس كمصدر آمن للري التكميلي دون زيادة وعي المزارعين للحد من الجوانب السلبية التي قد تؤثر على نوعية مثل هذه المياه وعلى النظام البيئي بأكمله.

تداعيات إستخدام مياه رديئة النوعية على التربة والنباتات النامية في منطقة شرق الدلتا

رسالة مقدمة من

محمود عبدالله علي

بكالوريوس علوم زراعية – قسم التربة – كلية الزراعة – جامعة البصرة (١٩٩٥)

كجزء من متطلبات الحصول على

درجة الماجستير فى العلوم الزراعية (أراضي و مياه)

قسم الأراضي و المياه - كلية الزراعة - جامعة بنها

<u>لجنة الحكم والمناقشة:</u>

أ.د. / أبو النصر هاشم عبد الحميد ....
أستاذ الأراضي المتفرغ – كلية الزراعة – جامعة بنها

أ.د. / أيمن محمد الغمري ....
أستاذ ورئيس قسم الأراضي – كلية الزراعة – جامعة المنصورة

أ.د. / إيهاب محمد فريد عبد السميع ....
أستاذ الأراضي – كلية الزراعة – جامعة بنها

د. / محمد حسن حمزة عباس ....
أستاذ الأراضي المساعد – كلية الزراعة – جامعة بنها

د./ مها محمد السيد علي ....
أستاذ الأراضي المساعد – كلية الزراعة – جامعة بنها

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وكيل الكلية للدراسات العليا والبحوث **عميد الكلية**

أ.د. ناصر خميس الجيزاوي **أ.د. محمود مغربي عراقي**

تداعيات إستخدام مياه رديئة النوعية على التربة والنباتات النامية في منطقة شرق الدلتا

رسالة مقدمة من

محمود عبدالله علي

بكالوريوس علوم زراعية – قسم التربة – كلية الزراعة – جامعة البصرة (١٩٩٥)

للحصول على درجة

الماجستير فى العلوم الزراعية

(أراضي و مياه)

<u>لجنة الإشراف العلمي :</u>

أ.د./ أبو النصر هاشم عبد الحميد ....
أستاذ الأراضي المتفرغ – كلية الزراعة – جامعة بنها

أ.د. / إيهاب محمد فريد عبد السميع ....
أستاذ الأراضي – كلية الزراعة – جامعة بنها

د. / محمد حسن حمزة عباس ....
أستاذ الأراضي المساعد – كلية الزراعة – جامعة بنها

كلية الزراعة
قسم الأراضي و المياه

تداعيات إستخدام مياه رديئة النوعية على التربة والنباتات النامية في منطقة شرق الدلتا

رسالة مقدمة من

محمود عبدالله علي

بكالوريوس علوم زراعية – قسم التربة – كلية الزراعة – جامعة البصرة – العراق (١٩٩٥)

للحصول على درجة

الماجستير فى العلوم الزراعية

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قسم الأراضى و المياه

كلية الزراعة

جامعة بنها

٢٠١٧