

Journal of Coastal Life Medicine

journal homepage: www.jclmm.com



Document heading

doi: 10.12980/JCLM.3.2015J5-4

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Assessment of agricultural drainage water quality for safe reuse in irrigation applications-a case study in Borg El-Arab, Alexandria

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ARTICLE INFO

Article history:

Received 15 Jan 2015

Received in revised form 21 Jan 2015

Accepted 2 Feb 2015

Available online 4 Feb 2015

Keywords:

Agricultural drainage water

Heavy metals

Irrigation

Water quality

ABSTRACT

Objective: To demonstrate the technical feasibility of the reuse of agricultural drainage water for irrigation.

Methods: The agricultural drainage water near Banjar El-Sokar, Borg El-Arab City, Alexandria, Egypt was collected. The measured heavy metals in the drainage water were compared with the permissible levels stated in environmental regulations, Law No. 48 of 1982 concerning the protection of the Nile River and waterways from pollution.

Results: Heavy metals and trace elements were detected in this agricultural drainage water as following: Al (1.64 mg/L), Ca (175.00 mg/L), Cd (1.87 mg/L), Co (2.23 mg/L), Cu (1.71 mg/L), Fe (1.64 mg/L), K (20.50 mg/L), and Pb (2.81 mg/L). According to allowable limits, item such as Fe is lower than permissible level of 3.00 mg/L, while Pb and Cu are higher than 0.10 mg/L and 1.00 mg/L, respectively.

Conclusions: Vegetables irrigated with such drainage water are not safe for human and animal consumption. Accordingly, the study suggests and recommends remediation of drainage water using physical, chemical and/or biological methods.

1. Introduction

In Egypt, nearly all water bodies, including groundwater, rivers, lakes as well as agricultural drainage water, are affected by pollution. This contamination is resulted from different pollution sources such as organic wastes, nutrients, trace elements and pesticides[1]. The high values of heavy metals would limit drainage water reuse or increase the mixing ratio between fresh and drainage waters[2]. Therefore, there is a crucial need to find all viable solutions to protect our current water resources and to deal with the water shortage problem[3]. However, management for safe reuse and disposal of water requires an understanding of the characteristics of the drainage water. Heavy metals in drains are mostly produced from industrial sources[4]. In Egypt, there has been a growing interest in the negative impacts of heavy metals on humans and

aquatic environments[5]. Therefore, policy and regulations for controlling water disposal containing heavy metals have been tightened[6]. Egypt has no single general law on integrated water resource management. However it has several sectorial laws and decrees, such as laws on water and environment: Law 93/1962, Law 48/1982, Law 4/1994, Law 9/2009, and laws and regulation for wastewater reuse: Law 93/1962, Law 44/2000, Decree 603/2002, Decree 171/2005, Decree 1038/2009 and Egyptian Code 501/2005[7]. The Law 93/1962 controls the reuse of wastewater in agriculture as described in the following rules: 1. it is prohibited to harvest yields, which were irrigated with a treated wastewater until two weeks after stopping irrigation; 2. it is prohibited to use treated wastewater, primary or secondary treatment, to irrigate cattle pasture; 3. it is acceptable to reuse treated wastewater in agricultural purposes, only if it would be conform to conditions and criteria mentioned in Law 93 /1962[8]. Moreover, Law 48/1982 and Decree 8/1993 protect the River Nile and waterways from pollution. Additionally, specific laws for irrigation, Law 12/1984 and Law 213/1994, define the use and management of public and private sector irrigation and drainage systems[9]. In order to divert considerable amounts of drainage water to newly reclaimed areas

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several projects have been undertaken by the Ministry of Water Resources and Irrigation[3]. For example, constructed engineered wetlands in El-Manzala was implemented to treat 25 000 m³ per day of water from Bahr El-Baqar drain. After treatment, the major portion of water is used for irrigation, while some are diverted into basins designed for fish farming. Moreover, in El-Salam, Canal Project treats 20 000 000 000 m³ of drainage water from Bahr Hadous and Lower Serw drains are mixed with 20 000 000 000 m³ fresh water from the Nile River (Damietta branch) to irrigate 92 500 hectares in the Eastern Nile Delta and 168 000 hectares in Sinai. Additionally, Umoum Project reuses 10 000 000 000 m³ of drainage water to irrigate 202 500 acres in El-Nubaria after mixing with fresh water. Currently, treatment technologies for drains have been implemented to reduce loads of heavy metals. Physical, chemical and biological methods such as ion exchange, reverse osmosis, solar ponds, chemical reduction with iron, microalgal-bacterial treatment, volatilization, biological precipitation, and flow-through wetlands, are well known solutions for adequate remediation. Accordingly, this study aimed at evaluating water quality of an agricultural drainage water in Borg El-Arab at Alexandria City. After that, remediation methods are recommended for safe reuse application for agricultural purposes.

2. Materials and methods

2.1. Study area

In this study, we chose the agricultural drainage water near Banjar El-Sokar, Borg El- Arab City, Alexandria, Egypt as the studied water source. The drain receives agricultural drainage and domestic wastewater. Additionally, untreated industrial wastewater including heavy metals is dumped daily into the drain.

2.2. Water sampling

Assessment of drainage water quality is necessary when reusing the water for irrigation purpose. Water samples were collected from the mentioned agricultural drainage water during four seasons of 2013. After collection, samples were transferred and conserved by standard methods for the examination of water and wastewater[10].

2.3. Water samples elemental analysis

Water samples were prepared for heavy metals determination by using inductively coupled plasma mass spectrometry, Agilent, United States. The pertinent elements involved in this study included Al, Calcium, Ca, Co, Cu, Fe, K, Mg, Na, and Pb. The elements were measured according to the standard methods for the examination of water and wastewater[10].

3. Results

Fe and Ca are chemical elements having atomic numbers equal to 26 and 48, respectively. As listed in Table 1, the drain contains Fe of 1.64 mg/L which is lower than the allowable limit (3.00 mg/L). Contradictory, Cd concentration of 1.87 mg/L is higher than the permissible level (0.03 mg/L). Ca is relatively water soluble compared to other heavy metals, whose toxicity to aquatic life is variable, even between closely related species. The actual dose of

Pb in the drain is 2.81 mg/L. Pb is considered as a toxic element for human when accumulated in the body. The allowable level of Pb should not be more than 0.10 mg/L. Al, Ca and Mg are chemical elements having atomic numbers equal to 13, 20 and 12, respectively. Al concentration in the drain is 1.64 mg/L, while the Ca and Mg concentrations are 175 mg/L and 135 mg/L, respectively. Al has controversially been concerned as a factor in Alzheimer's disease, as well as reduces plant growth on acid soils. Ca and Mg are essential as a major material for living organisms. However, those three chemical elements are not mentioned in modified executive regulations for Law of 48/1982, concerning the protection of the Nile River and waterways from pollution by Decree 92 of 2013, Item 51[11].

Table 1

Average concentrations of the heavy metals and trace elements for agricultural drainage water.

Parameter	Concentration (mg/L)	Permissible levels [*]
Al	1.64	----
Ca	175.00	----
Cd	1.87	Not more than 0.03 mg/L
Co	2.23	----
Cu	1.71	Not more than 1.00 mg/L
Fe	1.64	Not more than 3.00 mg/L
K	20.50	----
Mg	135.00	----
Na	234.00	----
Pb	2.81	Not more than 0.10 mg/L

^{*}: Source[11].

4. Discussion

4.1. Reuse of agriculture drainage water for irrigation

After irrigation with contaminated water, trace elements and heavy metals could be absorbed by plants; the main sources of heavy metals to vegetable crops are their growth media, especially agricultural drainage water if used for irrigation and even the air pollution from which the pollutants are taken up by the roots or foliage. Then these elements could be then transferred to human by eating[12]. Existence of heavy metals either at high or low concentrations must be effectively removed from the drains[13]. Fe concentration is lower than permissible level of 3.00 mg/L, while Pb and Cu are higher than 0.10 mg/L and 1.00 mg/L, respectively. Recent studies proved that metal contamination in drain water, plankton, and fish organs followed the order of Cu>Pb>Cd. Cd in water was found in higher concentrations than the reference values for irrigation purposes[14].

In Egypt, water quality standards have been developed governing the treatment of agricultural drainage water. The guidelines aim at protecting the natural environment from wastewater-related pollution. Report No. EPA-625/R-92-004 of United States Environmental Protection Agency lists some guidelines for the utilization of water in irrigation purposes[15]; in case of secondary disinfection for reclaimed waste water quality with chemical characteristics of biological oxygen demand of 30 mg/L, total dissolved solids of 30 mg/L and residual chlorine of 1 mg/L, food crops commercially processed could be irrigated with this water on a setback distance of 90 m to potable water supply and 100 m to areas accessible to the public in case of spray irrigation. In case of secondary filtration disinfection for reclaimed water quality with chemical

characteristics of daily turbidity of 1 nephelometric turbidity units and residual chlorine of 1 mg/L, food crops not commercially processed could be irrigated with this water on a setback distance of 90 m to potable water supply and 100 m to areas accessible to the public[15]. Also, in 2005, Egyptian Code for the Use of Treated Wastewater in Agriculture shows plants and crops irrigable with treated wastewater[13]; for example, palm, Saint Augustin grass, cactaceous plants, ornamental palm trees, climbing plants, fencing bushes and trees, wood trees and shade trees could be considered as the category of Grade One; nursery plants of wood trees, ornamental plants and fruit trees are considered as the category of Grade Two; caya, camphor and other wood trees are considered as the category of Grade Three. These codes may help in arranging usage of different types of waste water treated or not in plants irrigation.

4.2. Recommended agricultural drainage water treatment

4.2.1. Physical remediation

Ion exchange as a physical process involves the exchange of an undesirable dissolved constituent for a more desirable solute. This method is undertaken when pollutants are electrostatically attached to an ion exchange material, which can be either a synthetic resin, or a naturally occurring zeolite or activated alumina[16]. Generally, ion exchange system is widespread applied to reduce water hardness resulted from Ca and Mg. Accordingly, ion exchange is often used for specific ion removal rather than overall salinity elimination. Another physical approach known as distillation process relies on evaporation and condensation to demineralize water. However, this method consumes significant amount of energy than using reverse osmosis for sea water desalting. Additionally, membrane technology has been intensely applied for physical treatment. Examples of membrane water treatment processes include microfiltration (pore sizes of about 0.2 μm for solids removal), ultrafiltration (pore sizes 0.02 μm) and nanofiltration for removing divalent ions such as Ca, Mg and sulfate, as well as reverse osmosis that is effective for removing monovalent ions, such as Na and chloride. A by-product of the separation process of dissolved salt contents is brine that must be disposed of. In electro dialysis process, the electrically charged ions pass through the ion-exchange membranes by electric potential (voltage) as a driving force. In a study by Lin *et al.*[17], factors affecting sorption of B (III), Cu (II), Cr (VI), Pb (II), and Se (VI) from reverse osmosis concentrate were investigated. The iron-derived coagulation processes were effective due to formation of strong inner-sphere complexes between the metal cations and Fe/Al oxide surface sites, as well as attractive electrostatic interactions with the negatively charged solids surface.

4.2.2. Chemical remediation

Among the various treatment methods implemented to remove heavy and trace metals, chemical precipitation has been the most widely used technology. This process requires transformation of dissolved contaminants into insoluble solids. After that, the aggregates are subsequently separated from the liquid phase by

physical methods, such as clarification and/or filtration[18]. The type and dose of chemicals are mainly dependent on several parameters such as pH, alkalinity, turbidity and temperature. Generally, heavy metals in water are precipitated by adding lime or sodium hydroxide during neutralization. Additionally, granulated lime and calcium carbonate are used as coagulants. A combination of different processes such as chemical precipitation and ion exchange has been reported to be efficiently applied in heavy metal removal. Chemical treatment has an advantage to be convenient and self-operating, and requires low maintenance, with no need for complicated operators. However, the drawbacks are the large volumes of sludge generated, inducing additional waste-disposal costs. The addition of treatment chemicals may increase the amount of waste sludge up to 40%-50%. Macías *et al.* used a pilot multi-step passive remediation system to abate high concentrations of Zn together with Mn, Cd, Co and Ni below the recommended limits for drinking waters[19]. The complete trivalent metal removal was achieved by the employment of a limestone-based passive remediation technology followed by caustic magnesia powder dispersed in a wood shavings matrix.

4.2.3. Biological remediation

Biological remediation is a technology where microorganisms are used to break down organic compounds into harmless byproducts such as CO_2 , N_2 and H_2O [20]. This method is confirmed by existence of the appropriate microbial functional groups, such as nitrifiers, denitrifiers, sulfur reducing bacteria *etc.* The complex microbial community present in the biological facilities has a requirement for carbon, nitrogen and phosphorus for the maintenance of basal metabolism and cell growth[21]. The microbe induces a transfer of electrons from a donor compound of higher energy state (mainly organic carbon) to an electron acceptor of lower state for growth and reproduction. Biological nitrogen removal is achieved by nitrification, where ammonium is oxidized to nitrites and nitrates, followed by denitrification process, as nitrates are transferred to nitrogen gas. Practically, two different microorganisms-based methods are used for bioremediation, namely, microbial dosing method and biofilm method. Additionally, it has been documented that aquatic animals such as clam, snail or other filter-feeding shellfish had prominent effect on nutrients removal in eutrophic water body. Furthermore, aquatic plants can mitigate or fix water pollutants through adsorption, absorption, accumulation and degradation for purification. Manios *et al.* achieved percentage removal of 100% for Cu and Zn and almost 96% for Ni using *Typha latifolia*[22]. Aghakhani *et al.* investigated the ability of combinations of five adsorbents (peat, activated carbon, zeolite, anionic resin, and cationic resin) to remove chromium from an industrial wastewater containing 15.1 mg/L Cr (III) and 45.1 mg/L Cr (VI)[23]. Shaheen *et al.* studied the efficiency of low cost sorbents *i.e.*, chitosan, egg shell, humate potassium, and sugar beet factory lime for removal of Cd, Cu, Pb and Zn from wastewaters[24]. The study achieved metal removal of: 72%, 69%, and 60% to nearly 100% for Cd, Cu and Zn, respectively. Shi *et al.* investigated the efficiency of *Pannonibacter phragmitetus* on the reduction of Cr (VI) from aqueous solution, and found

maximum removal rate of 562.8 mg/L/h[25]. Miranda *et al.* studied Cr (VI) removal efficiency using two species of cyanobacteria, *Oscillatoria laetevirens* and *Oscillatoria trichoides*[26]. Of the two species, living cells of *Oscillatoria trichoides* were most effective, for which removal was 38.7 mg/g and reached 51.6% of the total Cr (VI) at 30 mg/L and pH 5–5.9.

The concentrations of heavy metals Cd, Pb, Cu and Cr were above the maximum permissible levels but Fe was lower than allowable limits in this agricultural drainage water, therefore vegetables irrigated with such drainage water are not safe for human and animal consumption. Remediation options for drainage water in this study, agricultural drainage water, near village Banjar El- Sokar, Borg El-Arab at Alexandria City were recommended.

Conflict of interest statement

We declare that we have no conflict of interest.

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