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FULL LENGTH ARTICLE

Performance evaluation of agricultural drainage water using modeling and statistical approaches

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Abstract This study assessed spatial variations in physical and chemical properties of an agricultural drain near Borg El-Arab city, Alexandria, Egypt. Pearson's correlation coefficient indicated that salinity had strong correlations with total dissolved solids (TDS) (r 0.999, p < 0.001) and Cl^- (r 0.807, p 0.016), whereas, pH was considerably affected by temperature (r 0.674, p 0.067), oxidation reduction potential (ORP) (r 0.866, p 0.006) and NO_3^- (r 0.731, p 0.039). Those results were further confirmed by applying an adaptive neuro-fuzzy inference system and regression models. Moreover, principal component analysis (PCA) indicated that PC1 explained 41.1% of the total variance, and had high loadings of TDS (0.46), salinity (0.46) and Cl^- (0.48). Additionally, PC2 accounted for 35.2% of the total variance, and had high loadings of pH (0.53), temperature (0.48), ORP (0.40) and NO_3^- (0.47). The present study revealed that artificial intelligence and PCA could be used to effectively reduce the number of physicochemical parameters that may assist in the description of drainage water quality. It is recommended that the current status of the drain is suitable for reuse in irrigation purposes except at few locations containing high salinity.

Introduction

Egypt is an arid country that faces challenges due to its limited water resources and disorders of water balance (Nasr and Zahran, 2015). The annual water budget from the Nile, rainfall along the Mediterranean Coast and deep groundwater accounts for approximately 57.7 billion m^3 (Barnes, 2014). The Egyptian ministry of water resources and irrigation (MWRI) reported that the expected total water demand, by 2050, would be 81.7 billion m^3 per year (MWRI, 1998). In order to fill the gap between supply and demand, reuse of agricultural drainage water should be practiced. The official reuse of agricultural drainage water in irrigation amounted to 4.84 billion m^3 per year in 2001, which is expected to reach 9.6 billion m^3 by the year 2017 (Abdel Wahaab and Omar, 2011). Unfortunately, large amounts of untreated urban municipal, industrial wastewater and rural domestic wastes are being discharged into the agricultural drains (MWRI, 1998). In this context, most of the drains have become an easy dumping site for all kinds of wastes, such as solid wastes, domestic wastewater and industrial wastes. Therefore, the

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suitability of drainage water for reuse in irrigation purposes should be intensively assessed (Nasr and Zahran, 2014).

In Egypt, drainage water is reused in three ways; i.e. naturally, officially and unofficially (El Gamal et al., 2005). Natural reuse of drainage water occurs when rivers or canals act as a drain for hydrologic basin aquifer systems (El Gamal et al., 2005). Official reuse occurs by lifting specific amounts of drainage water from drainage canals, and mixing them with main irrigation canals. The amount of water used for official reuse is controlled and managed by the MWRI (DRI, 1995). Unofficial reuse is practiced by individual farmers without pre-permission from MWRI (Allam and Negm, 2013). Water quality regulations of Egypt have been developed to govern the kinds of reuse (El-Kady and Elshibiny, 1999). The Egyptian guidelines aim at protecting the water bodies from wastewater-related pollution. The Egyptian rules are illustrated in several articles and reports as follows: law 48/1982 regarding the protection of the river Nile and waterways from pollution, law 12/1982 regarding the irrigation and drainage, ministerial decree 8/1983 on law 48/1982 concerning reuse of drainage water; and ministerial decree 44/2000 regarding the amendment of law 93/1962 on the drainage of liquid wastes (MALR, 2009; MWRI, 2005).

When wastewaters is dumped into natural water bodies without an appropriate treatment, organic matter is assimilated by aerobic microorganism, and dissolved oxygen (DO) is consumed with their growth (Gupta et al., 2014). If the supply of DO from air and photosynthesis is insufficient, the concentration of DO decreases. As the concentration of DO approaches zero, evolution of H_2S by anaerobic bacteria begins giving the water an unpleasant smell and taste. Under this environment, the living conditions for aerobic aquatic life deteriorate and species that can survive without DO become dominant (Gupta et al., 2015). For example, fish can only survive where the DO concentration is higher than 3 mg/L. Moreover, high levels of nitrogen and phosphorus cause eutrophication, leading to many problems such as toxic algal blooms, problems in water treatment works, deterioration of landscape and depletion of DO levels (Suthar et al., 2009).

Water quality is a description of chemical, physical and biological characteristics of water (El Gohary, 2015). It is generally assessed by the measurement of several parameters, such as temperature, pH, electrical conductivity (EC) and turbidity, in addition to various pollutants including, pathogens, nutrients, organics and metals (Abdel Azim, 2000). Previous researches studied the interaction effects among environmental parameters of surface water using artificial intelligence. For example, Banejad and Olyaie (2011) applied an artificial neural network (ANN) model for river water quality index (WQI) prediction. The study (Banejad and Olyaie, 2011) found that the optimum structure of neural network achieved high correlation coefficients for biochemical oxygen demand (BOD) and DO of 0.986 and 0.969, respectively. Additionally, Gazzaz et al. (2012) presented ANN modeling of the WQI for Kinta River (Malaysia) using water quality variables as predictors. The WQI included 36 parameters such as temperature, turbidity, EC, salinity, pH, DO, BOD, nitrogen (NO_3-N), and chloride (Cl). The study (Gazzaz et al., 2012) exhibited that the WQI predictions of this model had a strong positive correlation (r 0.977) with the measured WQI values.

Principal component analysis (PCA) is a useful statistical technique that has found application in the field of water quality assessment (Al-Sayed, 2015). PCA is a tool for multivariate data analysis used to extract relevant information from various datasets (Costa et al., 2009). PCA essentially rotates the set of points around their mean in order to align with the first few principal components (PCs) (Olsen et al., 2012). The first principal component (PC1) is the direction in space along which projections have the largest possible variance (Mishra, 2010). The second principal component (PC2) is the direction that maximizes variance among all directions orthogonal to PC1 (Mishra, 2010). Correlation analysis is another statistical tool that can be applied for understanding the water quality data. Pearson's correlation coefficient is a measure of the linear relation between two variables. It gives a value between +1 (a total positive correlation), zero (no correlation) and −1 (a total negative correlation) (Dinka et al., 2015). Regression analysis can also be used to develop a complete relationship between water quality parameters. It consists of a group of mathematical and statistical techniques based on the fit of empirical models to the actual data (Bezerra et al., 2008).

Therefore, this work investigated the water quality of a drain near Borg El-Arab City, Alexandria. The measured parameters included, pH, temperature, total dissolved solids (TDS), DO, EC, oxidation reduction potential (ORP), salinity, NO_3^- and Cl^-. Artificial intelligence and PCA were used to find the correlations and interactions among those parameters. To the best of our knowledge, our research is among the few studies that applied advanced modeling techniques for studying the combinations among environmental parameters.

Materials and methods

Sampling

Water samples were collected from eight locations (P-1 to P-8) along an agricultural drain near Borg El-Arab city (latitude 30° 54′ 03″ North and longitude 29° 33′ 02″ East), Alexandria, Egypt. The gathered samples were kept in clean 1 L polyethylene plastic bottles, and stored in an ice-box at 4 °C until transport to the laboratory for further analysis.

Analytical analysis

The parameters pH, temperature, TDS, DO, EC, ORP, salinity, NO_3^- and Cl^- were measured and recorded by multiparameter water quality meter – Aquaprobe® AP-7000, England. The analysis was conducted according to Standard Methods for the Examination of Water and Wastewater (Eaton et al., 2005).

Artificial intelligence

Adaptive neuro-fuzzy inference system (ANFIS) is a kind of ANN, which is based on Takagi–Sugeno fuzzy inference system (FIS). ANFIS has a potential to capture the advantages of both neural networks and fuzzy logic principles in a single structure (Guler and Ubeyli, 2004). The function *anfis* in MATLAB R2015b uses a hybrid learning algorithm to tune the parameters of a Sugeno-type FIS. The algorithm uses a combination of least-squares and back-propagation gradient