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COMBINED EFFECT OF WIND SPEED AND COVERING IRRIGATION CANALS ON WATER QUALITY PARAMETERS

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Wind has a considerable effect on many water quality parameters. Some of the parameters are directly affected by the wind, while others are influenced by other physical water parameters like the velocity, temperature. etc. that are affected by wind and hence transfer their effect to water quality parameters. As the wind has an effect on water quality parameters, also covering waterways has a great effect on the water quality of those covered waterways. This is because covering a waterway alters the concentrations of its water quality parameters. This research is concerned with studying the combined effect of wind and covering of canals on different water quality parameters. The main Sheikh Zayed canal of the New Valley project in Toshka governorate in Egypt is taken as case study. Water quality parameters studied are dissolved oxygen concentration (DO) and total dissolved solids (TDS). Mathematical model was developed in order to carry on the simulation. After simulating the effect of wind and covering on these two water quality parameters it was found that the studied water quality parameters concentrations increased as the wind is gradually increased. Thus, TDS and DO showed maximum increase with increased wind speed and with uncovered canal area. TDS showed the max increase; namely 16%.

Keywords: Dissolved oxygen, Total dissolved solids, Evaporation, Re-aeration.

1 INTRODUCTION

Wind has a direct effect on water. For example, if there is a windy day, the sea will have lots of waves and currents. Another effect is the re-aeration, which affects greatly the concentration of dissolved oxygen (DO) in water. Many studies were done simulating the effect of wind on evaporation. Davarzani *et al.* (2014) studied the effect of wind speed on evaporation from soil (Davarzani *et al.* 2014). Another study was done by Schouten *et al.* (2011) simulated the effect of variable wind speed on evaporation rates (Schouten *et al.* 2011). None or very rare studies addressed the direct relationship between wind speed and DO in water. As for the TDS many papers addressed the impact of numerous factors on TDS, but no paper was found to address the direct effect of wind on TDS. For example, the effect of turbidity on TDS was studied at the ANIMIDA report (Dunton *et al.* 2003). Also, Hart studied the impact of land use on TDS in water (Hart 2006). As for the covering effect on water quality parameters, very rare studies were done addressing that topic. The research paper of ElBaradei and AlSadeq (2019) addressed the direct effect on covering canals on water quality parameters. It is clear that studying combined effect of wind and covering canals on both DO and TDS needs to be studied. The study is implemented on Sheikh Zayed canal in Upper Egypt. It is a windy arid area that has excessive evaporation rates. Sheikh Zayed canal will be mainly responsible for irrigation in Toshka area. It takes water from Lake Nasser. The study focuses on the main canal with following dimensions: 50 km long; 54 m top width, 30 m bottom width, 7m depth including 1m of freeboard, and 2:1 side slopes.

2 RESEARCH ANALYSIS

2.1 Water Velocity Calculations

When wind blows over water it generates shear stress at water surface. Although this generated shear stress is typically very small; but when assimilated over large water body, it can have a large and drastic effect (Dean and Dalrymple 1991). The most common formulas used for estimating the shear stress generated by wind are those by Wu and Van Dorn (Van Dorn 1953, Wu 1969). The formula, which was developed by Wu is as seen in Eq. (1):

$$\tau = \rho_{air} * k_w * W^2 \tag{1}$$

where; τ is the wind stress exerted on water surface by wind (N/m^2), ρ_{air} is the mass density of air, W: is the wind speed in cm/s at 10 m height above water surface, and k_w is the wind speed dependent factor and it is calculated with as seen in Eq. (2).

$$k_w = \begin{bmatrix} windspeed < 100cm/s = 1.25/(windspeed/100)^{0.2} * 0.001 \\ 100cm/s < windspeed < 1500cm/s = 1.25/(windspeed/100)^{0.5} * 0.0005 \\ windspeed > 1500cm/s = 0.0026 \end{bmatrix} \tag{2}$$

whereas the formula which was developed by Van Dorn is as seen in Eq. (3) (Van Dorn 1953):

$$\tau = \rho_{water} * k_{vd} * W^2 \tag{3}$$

For this formula, K_{vd} is the wind speed dependent factor and it is calculated with as seen in Eq. (4):

$$k_w = \begin{bmatrix} W < W_c = 1.2*10^{-6} \\ W > W_c = 1.2*10^{-6} + 2.25*10^{-6}(1 - Wc/W)^2 \\ where \quad Wc = 5.6m/s \end{bmatrix} \tag{4}$$

The water velocity induced by wind could be calculated as seen in Eq. (5) (Reid 1957 and Dean 1991):

$$V = 2.5\sqrt{\frac{0.2\tau_{surface}}{\rho water}}\ln\left(\frac{11y_0}{k\,D_{50}}\right) \tag{5}$$

where v is the depth average velocity, $\tau_{surface}$ is the shear stress exerted on the water surface by the wind, y_0 is the water depth, k is the relative bed roughness (relative to the sediment grain size), and D_{50} is the median grain diameter. The constants in this equation are obtained from real data of Lake Nasser. So, k = 14 and D_{50} = 0.029 mm (Toufeek and Korium 2009).

2.2 Evaporation Calculations

The evaporation rate is calculated using the widely used model, Penman-Monteith (Penman 1948, Monteith 1965). Based on the study done by Elbaradei and AlSadeq (2019), the evaporation rate was calculated using three different evaporation models; and it was concluded that the Penman-Monteith was the most accurate equation (Elbaradei and AlSadeq 2019). The meteorological data used in calculations are in average daily form and are observed at the nearest station (Aswan weather station) to Toshka. Most of the meteorological data such as air temperature, wind speed, and vapor pressure are collected from the weather underground organization website (WUO 2016) while the shortwave data was observed by NASA (NASA 2016). The Penman-Monteith equation used is as seen in Eq. (6) (Penman 1948, Monteith 1965):

$$E = \frac{1}{\lambda}\left(\frac{\Delta w * (Rn - G) + \gamma * f(u) * (e_w - e_a)}{\Delta w - \gamma}\right) \tag{6}$$

where E is the open water evaporation rate (mm/day), λ is the latent heat of vaporization (MJ/kg), Δ_w is the slope of the temperature saturation water vapor curve (kPa/°C), R_n is the net radiation (MJ $m^{-2}day^{-1}$), G is the change in heat storage in the water body (MJ/m^2/day), f(u) is the wind function (MJ/m^2/day/kPa), e_w is the saturated vapour pressure at water temperature (kPa), e_a is the vapor pressure at air temperature (kPa), and γ is the psychometric constant (kPa/°C).

2.3 General Water Quality Variables Calculation Procedures

The Mass balance for each water quality variable is modeled over the control volume can be seen in Figure 1.

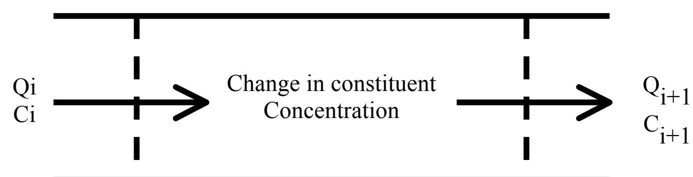

Figure 1. Control volume representing the mass balance concept.

$$C_{i+1} = \frac{Ci \cdot Qi + \Delta C}{Qi + 1} \tag{7}$$

As seen in Eq. (7), where C_i is the initial constituent concentration, Q_i is the initial volume flow rate, C_{i+1} is the final constituent concentration, Q_{i+1} is the final volume flow rate, and ΔC is the change in the constituent concentration. The total length of the canal is 50 km and it is divided into control volumes 100 meters long each, the concentration is calculated over each control volume, and the obtained values at the end section of the canal are shown in the results section.

2.4 Total Dissolved Solids Concentrations Simulation Procedures

Total Dissolved Solids (TDS) is a measure of all dissolved substances in water. TDS is a vital water quality parameter that affects aquatic animals and plants. The TDS concentration is changing due to the change in water volume. So, the evaporation is the main influencer. The calculations are based on the assumption that there is no account for the change in dissolved solids due to chemical reactions thus the evaporation is the main influencer. Then the TDS concentration is calculated using mass balance equation along the channel. The mass balance equation as seen in Eq. (8) for calculating TDS could be written as follows:

$$C_{i+1} = \frac{C_i * Qi}{Q_{i+1}} \tag{8}$$

where $Q_{i+1} = Q_i - Q_{evaporation,}$ where the $Q_{evaporation}$ is the evaporation that happened over the control volume. It should be noted that optimum value of TDS according to the WHO is 300mg/l or less.

2.5 Dissolved Oxygen Concentrations Simulation Procedures

The DO concentration is modeled in summer, which represents the highest temperature and lowest DO concentration. The DO concentration is calculated using the most widely used model Streeter-Phelps equation. The calculations consider both the change in wind speed and the change in re-aeration coefficient due to covering. The Streeter-Phelps formula is as seen in Eq. (9) (Streeter and Phelps 1925):

$$D = k_d \left(\frac{kd * Lo}{kr - kd}\right)(e^{kd*t} - e^{kr*t}) + Do * e^{kr*t} \tag{9}$$

where, as seen in Eq. (10) and Eq. (11), D is the oxygen deficit in water (mg/l), L is the BOD concentration in water (mg/l), Lo is the initial BOD concentration in water (mg/l), K_d is the coefficient rate of biochemical decomposition of organic matter (day^{-1}), K_r is the re-aeration rate coefficient (day^{-1}), t is the travel time in the stream interpreted as t=x/v, where x is the distance (m), and v is the mean flow velocity of the stream (m/s).

$$L = L_o e^{kd*t} \tag{10}$$

$$D_o = DO_{sat} - DO_o \tag{11}$$

$$DO_{sat} = 14.61996 - 0.4042T + 0.00842T^2 + 0.00009T^3 \tag{12}$$

where; as seen in Eq. (12), DO_{sat} is the saturation oxygen concentration of water (mg/l) and T is the water temperature (^oC). It has to be noted that the DO international standard for rivers and canals is 5 mg/l or more.

2.6 Initial Conditions

The daily average wind speed at Aswan weather station, varies between 2.8m/s and 3.82m/s, at 10 m height above mean sea level. The average air temperature in summer is 33^{o}C. The measured initial concentrations of DO, BOD, and TDS at Toshka station in summer are 5.5 mg/l, 3 mg/l, and 160 mg/l respectively.

2.7 Model Validation

The mathematical models developed used Excel sheets for simulation. The evaporation rate and TDS are validated against real values measured by the Ministry of Water Resources and Irrigation at Toshka station. The validation result shows a negligible error of 2% (Elbaradei and AlSadeq 2019) and 0.001% respectively. For DO, the developed excel sheet of the DO simulation is validated against the example developed by Chapra in his book (Chapra 1997). The validation of DO gave an exact result with zero percentage error (Elbaradei and AlSadeq 2019).

3 RESULTS

3.1 Water Velocity and Evaporation Rate Variations

The average flow velocity of the Canal is 1.2 m/s. By considering the wind speed variation effect, the average monthly water velocity is determined by Eq. (5), and shear stress is calculated by Eq. (1) and Eq. (3). The Van Dorn equation is used in the further calculations due to its higher estimate of water velocity. By increasing the wind speed with 10% increments, the monthly flow velocity is calculated. The flow velocity increases corresponding to the increase in wind speed due to the increase in shear stress at the surface layer. The flow velocity increases from 1.248 to 1.308 and the average evaporation rate increased from 8 mm/day to 10 mm/day corresponding to 0% to 100% increases in wind speed, respectively as can be seen in Figure 2. The relation between water velocity and evaporation rate with wind speed are modeled linearly. This approximation is valid as in this research paper a trend is investigated rather than an exact relation between the simulated variables and wind speed.

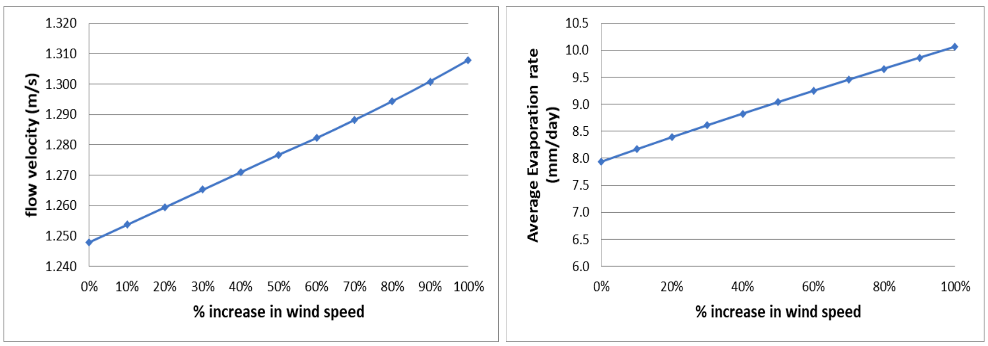

Figure 2. Average yearly flow velocity and evaporation rate fluctuations vs. % increase in wind speed.

3.2 Effect of Wind Speed on TDS and DO Concentrations

Due to increase in wind speed from 0% to 100%, evaporation rate increased from 8mm/day to 10mm/day. And based on the assumption of no change in TDS due to chemical reactions, the TDS concentration is mainly affected by the water volume flow rate, which is directly affected by evaporation volume. TDS concentration fluctuations for each percentage covering are plotted in Figure 3. The maximum increase of TDS concentration is 160.2 mg/l at totally uncovered canal due to maximum evaporation volume, while at totally covered canal, TDS concentration remains constant as there is no evaporation. As wind speed increases, DO concentration increases due to the increase of re-aeration rate; as well as, the increase in water velocity. As wind speed increases between 0% – 100%, the DO increases between 5.092 – 5.102 mg/l at the totally uncovered canal and between 4.475 – 4.523 mg/l at the totally covered canal, Figure 3.

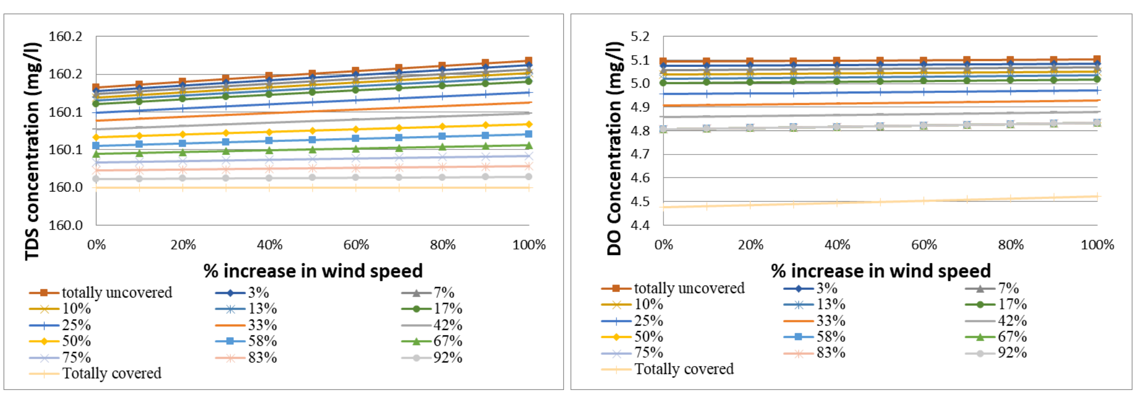

Figure 3. TDS & DO concentrations fluctuations vs. increase in wind speed for different coverages.

4 CONCLUSION

To conclude, wind speed is directly influencing velocity of water in channels. In Toshka area, where Sheikh Zayed Canal is located; it was found that by increasing wind speed from 10% to 100%, the maximum water velocity increases by 5%. As for the TDS, it showed significant variation with wind speed increase especially when the canal is totally uncovered. This is due the huge amount of evaporation in Toshka as it is in an arid region. The TDS increased by 16.225% corresponding to 100% increase in wind speed. DO concentration varied between 5.092 – 5.102 mg/l at the totally uncovered canal and between 4.475 – 4.523 mg/l at the totally covered canal corresponding to the increase in wind speed from 0% to 100%. Although the increase in DO concentration is not too much, it might be significant in larger water bodies.

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