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Valuing of Wadi El-Rayan ecosystem through water–food–energy nexus approach

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ABSTRACT

Wadi El-Rayan Protected Area (WERPA) is considered a model protectorate and an ecological restoration success. Development and mismanagement of Wadi El-Rayan vulnerable water resources could lead to the depletion of two artificial lakes and large scale deterioration of ecosystem health. We quantify the environmental value of preserving WERPA by applying the water–food–energy nexus approach and the concept of non-monetary opportunity cost. Three output indicators: agriculture, aquaculture and net energy production are selected to assess the value of different ecosystem health conditions under three water management scenarios. STELLA object oriented modeling environment has been used to simulate the scenarios that led to favorable, satisfactory, and critical ecosystem health conditions. The results demonstrated that the economic output that could be realized by reaching the favorable condition has twice the value of the acceptable condition.

1. Introduction

In 2000, the Global Water Partnership defined Integrated Water Resources Management (IWRM) as "a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (GWP, 2000). This article describes an integrated evaluation of resource management in Wadi El-Rayan based upon the consideration of the *water–food–energy nexus* approach combined with the concept of *non-monetary opportunity cost*, to achieve a harmonised use of water and energy for sustainable food production within a healthy ecosystem. The water, energy and food nexus implies that water availability, energy production/consumption and food security are inextricably linked, and that actions in any one area have impacts in one or both of the others (Hoff, 2011). Several examples can be given of the nexus, defined as a "resource trilemma" (Conway et al., 2015). Water can produce energy as it flows downhill, but it requires energy to be uplifted, when used for irrigation, and it may need to be purified through microfiltration or desalination when needed for drinking water supply and sanitation. Both water and energy are essential resources that are necessary in food production and for poverty alleviation; in case of food surplus, crops and side products of crop production can be used for generating energy as biofuels; it should be reminded that, conversely, water is essential for cooling power plants during energy production. Groundwater is increasingly used to respond to residential water requirements,

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however the sinking of groundwater tables increases the cost of agricultural production. Addressing integrated and nexus issues requiring multidisciplinary competences typically challenges governmental departments that tend to operate according to sectors that are identified under major themes (environment, water and irrigation, energy, agriculture) and that at times tend to compete among each other. More than 85% of Egypt's water resources are used in agriculture (Nour El Din, 2013); while new water resources are being explored (fossil groundwater, wastewater reuse, desalination, . . .) the nexus approach contemplates profiling the interlinkages between resource availability and resource use at landscape scale. In parallel to this, an assessment of water and energy requirements involved in the production of 42 crops commonly cultivated in Egypt was recently proposed as a strategy to identify optimal cropping patterns minimizing water and energy opportunity costs and maximizing agricultural productivity (El-Gafy, 2017).

The implementation of the nexus approach is proposed in this article as a gap bridging step between hydro-technical and ecological approaches to water resources management (Zalewski, 2014).

1.1. Description of the study site

El-Fayoum Governorate consists of an isolated depression of the Western Desert receiving approximately 2300 million cubic meters per year of water for irrigation through the Bahr Youssef canal, as the sole water supply. The only outlet of El-Fayoum is represented by Lake Qarun, which has no outflow and is under an average annual evaporation rate of about 2000 mm. The evaporation of 425 mcm out of the 700 mcm of drainage it receives per year, contributes to maintain an average lake level of 43.8 m below mean sea level. Two drains, El-Batts from East, and El-Wadi from West, contribute roughly 500,000 tons of salt per year. Accumulated salts and anthropogenic pollutants threaten Lake Qarun water quality as well as El-Fayoum ecosystem at larger scale. Water salinity increased from 11,200 to 36,000 mg/L, over the last century and it was expected to lead to negative impact on fishing, recreation, agricultural production and tourism. In 1973, MWRI diverted the El-Wadi drain toward Wadi El-Rayan, located 65 km South-West of El-Fayoum town. This resulted in the formation of two large artificial lakes (upper lake (Lake 1) is 11.4 m deep and 49.48 km^2 large; lower lake (Lake 2) is 8.8 m deep and 55.4 km^2 large) divided by a series of falls with an overall altitudinal difference of 22 m. Presently, 60% of El-Wadi drainage is diverted to Wadi El-Rayan while 40% is discharged into Lake Qarun.

Wadi El-Rayan Protected Area (WERPA) occupies 1759 km^2 in a depression of the South-western portion of El-Fayoum governorate (EEAA, 2002; Fayoum Governorate, 2014) between Longitude 29° and 29°24′11″ E and Latitude 30° and 30°34′ N (Fig. 1). It receives its water supply through an open diversion canal (El-Makshoofa Canal) stemming from El-Wadi drain and followed by Wadi El-Rayan tunnel (Fig. 2), which pours into the first depression (Lake 1). The maximum flow that can pass through the tunnel is 12 m^3/s, while El-Makshoofa Canal (9.0 km) has an average flow of 8.1 m^3/s (HRI, 2004). There are three mixing stations on El-Makshoofa Canal upstream WERPA feeding tunnel, each consisting of three pumping units:

- El-Nazla station, mixing fresh water from Bahr El-Nazla canal with drainage water (in ratio 1:4) for the irrigation of 8820 ha.
- El-Banat station, mixing fresh water from Bahr El-Banat canal with drainage water (in ratio 1:4) for the irrigation of 8400 ha.
- El-Gas station mixing fresh water from Bahr El-Gas canal with drainage water (in ratio 1:12) for the irrigation of 12,180 ha.

In 1989, a protected area was instituted in Wadi El-Rayan under Law 102/1983 by a decree of the Prime Minister (No. 943), to be managed by the Nature Conservation Sector (NCS) of the Egyptian Environmental Affairs Agency (EEAA). Before the 1973 diversion, the biodiversity of WERPA was severely affected, but it became restored upon the creation of the two lakes. The appearance of a large water body in the Wadi El-Rayan hyper-arid area attracted new species of plants, invertebrates, birds and mammals (Table 1, EEAA, 2002). The drainage intervention restored the natural ecosystem re-establishing its processing and regulatory functions for the benefit of biodiversity.

Development around the boundaries of WERPA is threatening biodiversity and ecosystem health. Paleczny et al. (2007) stated that the ecological condition of El-Rayan lakes has worsened over the last five years due to declining water levels and worsening water quality. They recommended to stop agricultural development within WERPA and to reduce upstream drainage water reuse until favorable water levels were attained in both lakes. The WERPA environmental status report presented by the Cooperative Union of Egyptian Water Resources in 2003 (CUEWR, 2003) mentions that the upper and the lower lake reached critical annual average values of 8.75 and 32.0 m b.m.s.l. The upper lake fluctuated by 40 cm per year in response to variation in drainage inflow and evaporation, while the lower lake was continuously decreasing due to drainage reuse for agriculture (1680 ha) and aquaculture (378 ha). In 2005, monitoring of diffuse pollution in Wadi El-Rayan reported 1000 mg Total Dissolved Solids/L at the inlet and as much as 9000 mg/L within the lakes (Mott MacDonald, 2006), values that are well above drainage water standards set by Egyptian Law No. 48/1982, as well as international water quality standards. Ammonium concentrations also exceeded, while dissolved oxygen and nitrate were within the national norm established for drainage waters. Pesticides concentrations were mostly below detection.

Water resources management options were assessed during a study conducted in 2004 by the Hydraulic Research Institute (HRI), National Water Research Center (NWRC) (HRI, 2004); alternative lake level scenarios were explored reflecting modeled water abstractions required for agriculture and aquaculture, as well as upstream reuse