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Review

Reusing oil and gas produced water for irrigation of food crops in drylands

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ABSTRACT

Water scarcity severely affects drylands threatening their food security, whereas, the oil and gas industry produces significant and increasing volumes of produced water that could be partly reused for agricultural irrigation in these regions. In this review, we summarise recent research and provide a broad overview of the potential for oil and gas produced water to irrigate food crops in drylands. The quality of produced water is often a limiting factor for the reuse in irrigation as it can lead to soil salinisation and sodification. Although the inappropriate use of produced water in irrigation could be damaging for the soil, the agricultural sector in dry areas is often prone to challenges in soil salinity. There is a lack of knowledge about the main environmental and economic conditions that could encourage or limit the development of irrigation with oil and gas effluents at the scale of drylands in the world. Cheaper treatment technologies in combination with farm-based salinity management techniques could make the reuse of produced water relevant to irrigate high value-crops in hyper-arid areas. This review paper approaches an aspect of the energy-water-food nexus: the opportunities and challenges behind the reuse of abundant oil and gas effluents for irrigation in hydrocarbon-rich but water-scarce and food-unsecured drylands.

1. Introduction

The oil and gas (O&G) industry produces large volumes of water during the extraction, processing, and refining of hydrocarbons. The water that is brought to the surface with hydrocarbons during extraction is termed ‘produced water’ (PW); this often comprises both formation water (which naturally occurs in significant quantities in the reservoir with the hydrocarbons) and water that has been withdrawn from another source, injected into the O&G reservoir, and returns to the surface with the hydrocarbons (e.g. water injected for enhanced oil recovery and for hydraulic fracturing) (Engle et al., 2014). In terms of volume, PW is by far the largest by-product or waste stream associated with the O&G industry (Veil, 2011). In certain conditions, PW can be reused for beneficial purposes such as agricultural irrigation, but, the volume of PW currently reused this way represents only a small proportion of the total PW generated. Nonetheless, beneficial reuse of PW is growing (Burnett, 2004; Clark and Veil, 2015) and could provide a substantial volume of irrigation water to crops located near O&G facilities in drylands (Guerra et al., 2011).

In this paper, drylands are defined by a precipitation to potential evapotranspiration ratio below 0.05 i.e. hyper-arid climate, up to 0.65 i.e. dry sub-humid climate (Barrow, 1992; FAO, 2016; Safriel et al., 2006). Many drylands contain massive hydrocarbon resources (e.g. the Persian Gulf, the Western USA, the Gulf of Mexico, the Libyan Desert or the Caspian Sea countries). There are also large coal resources from which gas and synthetic fuels are produced in the USA, China, Australia, and South Africa (Fig. 1). The Middle-East North Africa region, which is one of the most populated dry areas (World Bank, 2016); represents about 33% of the oil production and 23% of the gas production in the world (EIA, 2016).

Drylands occur on all continents (Safriel et al., 2006), cover 41% of the earth’s landmass (Millenium Ecosystem Assessment, 2005) and are projected to expand, partly due to climate change (Feng and Fu, 2013). These regions are inhabited by 2.1 billion people, many of whom live in developing countries and are directly dependent on the land’s natural resources (UN, 2010). Projections estimate that half of the global population will live in regions with high water scarcity by 2030 (UN, 2012). Drylands are an important component of the total agricultural land area as well. About 50% of the arid and semi-arid area is used for agriculture (Gratzfeld, 2003), drylands grow 44% of the world’s food and support 50% of the world’s livestock (Reid, 2014). In drylands, agriculture represents a major economic activity and approximately a third of the population living in these zones depend on agriculture particularly in Africa and in Asia (CGIAR, 2015). Within developed countries, drylands have also significant economic importance. For instance, California represents 13% of the US GDP making this dry state the major contributor to America’s national wealth (US Department of Commerce, 2015). California also produces around 70% of the fruit and

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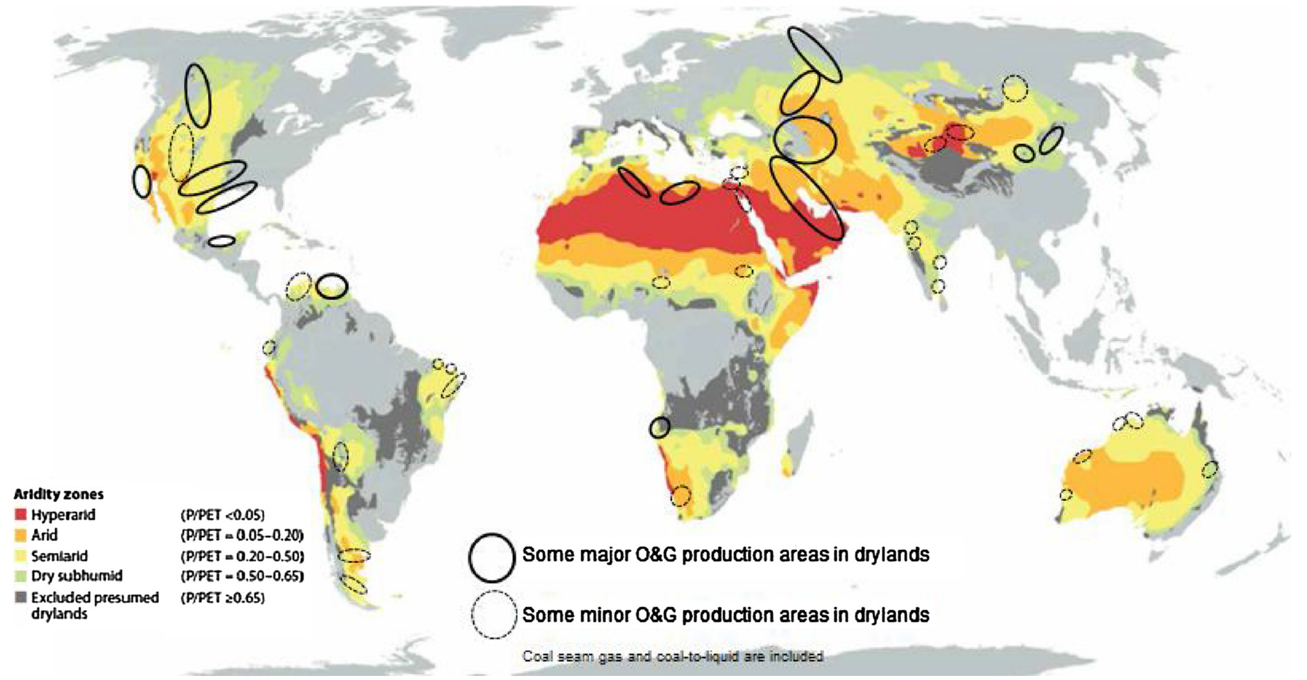

Fig. 1. Distribution of drylands and of the main oil and gas production zones located in these areas (adapted from FAO, 2016).

tree nuts, 55% of the vegetables, 10% of the cotton and about 30% of the rice produced in the USA (US Department of Agriculture, 2015). However, agriculture and populations in drylands are under constant threat of water shortage. In fact, drylands are characterised by physical water scarcity because they are naturally prone to lack of water due to their negative water balance (i.e. low precipitation and high evapotranspiration) (Gassert et al., 2014). In addition, fresh water availability can also be reduced by water pollution (NSW Government, 2011) or seawater intrusion (Qadir and Sato, 2015) which can contaminate the already limited fresh water resources. Climate change is projected to increase water scarcity in most drylands, affecting both rain-fed and irrigated agriculture (Pedrick, 2012). As water resources are diminishing, water users (i.e. industry, agriculture, households and the natural environment) are competing more and more for access to water (El-Zanfaly, 2015; Freyman, 2014; Qadir and Sato, 2015).

Therefore, the pressure on water resources from the O&G industry in drylands is expected to intensify and is likely to exacerbate competition and conflicts between water users, and especially between irrigated farming and unconventional O&G firms which use fresh water resources (Galbraith, 2013; Hitaj et al., 2014). Reusing O&G PW for the irrigation of food crops could contribute considerably to improve the sustainability of irrigated agricultural systems in drylands.

This structured review paper aims to provide a critical review of the potential of O&G PW for the irrigation of food crops in drylands. It starts by providing a review of the volumes and qualities of PW from around the world, followed by a discussion of its treatment and management practices. Finally, the potential for reuse of PW in agriculture is discussed and experiences of irrigation with PW are reviewed in order to identify the main risks associated with using PW in practical conditions. The quality of PW is also discussed from an agricultural viewpoint in order to highlight the agronomic and environmental risks associated with reuse and the perspectives for adapting PW to irrigation.

2. Volume of produced water

The water-to-oil (WOR) and water-to-gas (WGR) ratios are indicators used to quantify the volume of PW generated compared to the volume of oil or gas produced. Although strictly dimensionless, the O&G industry generally expresses the ratios as barrels (159 L) of water per barrel of oil or million cubic feet of gas. At the world scale, the average WOR was about 3:1 in the 2000s (Khatib and Verbeek, 2002), and is probably nowadays closer to 4:1, but it can locally range from as low as 0.4 to as high as 36 (Table 1) depending on the field history, the type of hydrocarbon and the technologies employed (Clark and Veil, 2015). Globally, this ratio has been increasing because conventional O&G fields are ageing, so they produce more and more PW for less hydrocarbons (Healy et al., 2015; Veil et al., 2004). Thus, the highest WOR and WGR are generally related to mature production areas (e.g. California, China, and Oman). However, the WOR and WGR of some fields in the Middle East are still low even if they have been operated for several decades due to specific geological and management conditions of these 'giant fields' which reach their maturation stage much later than smaller fields (Sorkhabi, 2010; Sorrell et al., 2011).

Significant quantities of PW are generated in dry regions (Table 1), although little information is available about volumes of PW in O&G producing countries. Indeed, the only significant O&G producer holding public documented information about PW generation and management is the USA (Clark and Veil, 2015, 2009). Contrary to hydrocarbon production that has a high economic value, PW volume is often not measured and monitored by O&G operators (Clark and Veil, 2009). As a consequence, the data in Table 1 are uncertain due to lack of rigorous reporting and monitoring (Clark and Veil, 2015).

The volume of PW and its evolution over time differ between oilfields and gas fields as oil reservoirs usually contain larger volumes of water than gas reservoirs as gas has a higher compressibility and sorption capacity than oil, and also because gas is stored in less porous reservoirs (Guerra et al., 2011). The volume of PW and wells' behaviour are also very heterogeneous between the types of production; conventional O&G wells typically show a gradual increase of water production while hydrocarbon production is decreasing (Clark and Veil, 2009; Healy et al., 2015). In contrast, in unconventional O&G production, the volume of PW tends to be correlated with the volume of hydrocarbons extracted (Healy et al., 2015).

Globally, the estimated quantity of PW has increased by more than 78% between 1990 and 2015 from about 10.6 billion m^3 to 18.9 billion m^3 compared to 38% growth of the oil production from 3.7 billion m^3 to 5.1 billion m^3 respectively. This increasing trend is expected to continue as the projected world PW volume is between 29–54 billion