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Managing the water resources problems of irrigated agriculture through geospatial techniques: An overview

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ABSTRACT

The intensification of irrigated agriculture is a prerequisite for fulfilling the rising food requirements of the burgeoning global population. But the expansion of irrigated agriculture causes the water resources problems in irrigated areas. The twin menace, i.e., waterlogging and soil salinization of irrigated agriculture can be managed by either adopting preventive measures which decrease the inflow or by employing remedial measures which increase the outflow of water and salt. Remote sensing and geographic information systems (GIS) are very useful tool and offer a good option to traditional techniques in monitoring and evaluation of waterlogged and saline areas. This paper presents an overview of the applications of remote sensing and GIS techniques for the management of water resources problems of irrigated agriculture. The indication and background of the water resources problems are provided. The integrated use of remote sensing and GIS techniques in the management of water resources problems are also discussed. Finally, the case studies of applications of integrated remote sensing and GIS approach and some conclusions are presented.

1. Introduction

The assured supply of water as and when required by crops is a prerequisite for sustainable food production for the burgeoning global population (Singh, 2014a, 2016a), which is likely to reach at the level of 9.7 billion persons in 2050 from the current 7.4 billion (United Nations, 2015). This increase in population needs about 60% more foods (FAO, 2013). The properly managed irrigated agriculture will provide more food in future as its share in world food production will increase to above 45% by 2030 from the current level of 40% (Singh, 2014b). In arid and semiarid regions, the crop water requirements is mainly supplied by supplemental irrigation as precipitation is not reliable, and is highly erratic both in quantity and in distribution (Postel, 1999; Jalota and Arora, 2002; Belaqziz et al., 2013; Consoli and Vanella, 2014; Singh, 2010, 2014c; Peragón et al., 2015). For example, the mean annual precipitation in India is estimated at 1160 mm, which ranges from 11,690 mm at Mousinram, a village in Meghalaya State to 150 mm at Jaisalmer, a district in Thar Desert of the Rajasthan State (Singh, 2012a). Even in regions where average water quantity may be sufficient, periods of surplus and deficit water availability can occur, as about 75% of the mean annual precipitation is received during four months (June–September) of the monsoon season. Though, irrigation water transportation from outside of the natural hydrological cycle increases the food production, it also causes the water resources problems, i.e., waterlogging and salinization, in irrigated areas (Thayalakumaran et al., 2007; Singh, 2011; Arslan, 2012; Singh and Panda, 2012a).

The twin menace of waterlogging and salinization of irrigated agriculture have negatively affected the productivity of arid and semiarid regions since the rise and fall of Mesopotamia (Jacobsen and Adams, 1958). Tanji (1990) and Hillel (2000) reported that the Sumerian civilization failed as agricultural productivity began to decrease due to waterlogging and salinization. The waterlogging problem lowers the yield in fertile soils and wastes water which is a critical input. The estimates of global size of irrigation induced soil salinity differ, but there is general agreement that the twin hazards represent serious threats to the sustainability of irrigated agriculture in many arid and semiarid regions (Bowonder and Ravi, 1983; Kalubarme et al., 1985; Ghassemi et al., 1995; Bradd et al., 1997; Bahceci et al., 2006; Akkaya Aslan and Gundogdu, 2007). Hoffman and Durnford (1999) reported how these twin problems have developed worldwide since recorded history, and the speed with which they are advancing at present. Kovda (1980, 1983), Barrow (1991), Szabolcs (1992), Abrol (1999), and Singh et al. (2010) have reported that the waterlogged area is increasing

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worldwide mainly as a result of the rapid expansion of irrigated agriculture since 1950s (Singh, 2014d).

The waterlogging and salinization problems in various irrigation command areas of Afghanistan, Argentina, Australia, Canada, China, Egypt, India, Iran, Iraq, Kampuchea, Netherlands, Pakistan, Peru, Saudi Arabia, South Africa, Syria, Thailand, Tunisia, Turkey, USA, and Vietnam have been studied by many researchers (e.g., Kinawy, 1977; Speece and Wilkinson, 1982; Sondhi and Sharma, 1987; Micklin, 1988; Bouwer et al., 1990; Sarma et al., 1990; Chitale, 1991; Levintanus, 1992; Kharin et al., 1993; Dregne et al., 1996; Xiong et al., 1996; Moore and McFarlane, 1998; Spoor 1998; Woodall and Ward, 2002; Collaku and Harrison, 2005; Houk et al., 2006; Jansen et al., 2006; Sheng and Xiuling, 2007; Askri et al., 2010; Singh, 2012b; Fei et al., 2014; Mercau et al., 2016; Velmurugan et al., 2016). Chaudhary et al. (1974), Kruse et al. (1993), and Singh (2015a,b) have reported that the presence of a saline shallow watertable is one of the major causes of root zone salinity in the irrigated areas.

Many experiments have been conducted in the past to examine crop water use from saline as well as non-saline shallow watertables and its impact on waterlogging and salinization management (Saini and Ghildyal, 1977; Ayars and Schoneman, 1986; Sharma et al., 1994; Kahlown et al., 2009; Singh and Panda, 2012b, 2013; Singh, 2016b). McFarlane and Williamson (2002) studied the causes of waterlogging and salinity in the 'Ucarro' experimental catchment of southwestern Australia. They concluded that waterlogging may be the more serious inhibitor for plant growth than salt even at low salt levels. Similar views have been expressed by Konukcu et al. (2006), who gave a sustainable solution to waterlogging and salinity problems in irrigated Lower Indus Basin of Pakistan where wheat and cotton are the main crops. Kitamura et al. (2006) analysed the causes of farmland salinization in the Aral Sea basin-research in the arid area of Japan. They suggested to avoid mixed cropping with rice and upland crops and unify either upland crops or rice in an irrigation block to control salinity and groundwater table and to decrease conveyance and field application losses by the introduction of canal lining, and improved land-leveling. Recently, Singh (2016b) simulated the long-term effect of different policies for managing the waterlogging and salinization problems of an irrigated semiarid area of India. The study suggested the implementation of suitable water management strategies, i.e., reduced canal water use, canal lining, increased groundwater use, and changed cropping patterns with reduced rice area, to moderate the water resources problems of the region.

During the last three decades researchers have extensively used remote sensing and GIS techniques for the solution of water resources problems of irrigated agriculture (e.g., Sanware et al., 1988; Kamaraju et al., 1995; Teeuw, 1995; Choubey, 1998; Brahmabhatt et al., 2000; Chowdary et al., 2008; Quan et al., 2010; Aslam et al., 2015; Oikonomidis et al., 2015; Zewdu et al., 2015; Elhag 2016; Muller and van Niekerk, 2016). As far as the author is aware, there has not been a review on the applications of geospatial techniques for managing the waterlogging and salinity problems, during the recent past. This paper, therefore, presents an overview of the applications of remote sensing and GIS techniques for the management of water resources problems of irrigated agriculture.

First, the paper provides an overview of the water resources problems of irrigated agriculture and the significance of the study. The background of the problems is presented. The integrated use of remote sensing and GIS techniques in the management of water resources problems are then discussed. The last sections deals with the case studies of applications of integrated remote sensing and GIS approach and some conclusions are presented.

2. Background

Irrigation-induced waterlogging and salinization occur over a vast region throughout the world (Abrol et al., 1988; Doering et al., 1999; Güler et al., 2014; Singh, 2015c; Wichelns and Qadir, 2015). Qureshi et al. (2008) estimated that about 30% of the cultivated lands downstream of the Indus Basin are threatened by waterlogging and salinity problems. Inadequate drainage systems, seepage from unlined earthen canals, and percolation from irrigation fields are the main causes for the problems in the basin (Mehta, 2000). El Gabaly (1972), Gad and Abel-Samei (2000), and El Baroudy (2011) have reported the waterlogging and salinity problems in the Nile Delta region. Singh et al. (2012) estimated that about 500,000 ha of Haryana, India are waterlogged and the problem is spreading in more canal-irrigated areas and creating hydrologic imbalances. Joshi and Tyagi (1994) have reported that nearly seven million ha of cultivated land in India are affected by waterlogging and salinity problems. Earlier, Bhattacharya (1992) reported an area of 3.3 million ha under waterlogging in India. Abul-Ata (1977) has reported that waterlogging and salinization problems have rapidly increased in Egypt after irrigation system was converted from seasonal to year-around following the construction of High Dam. Later, Wichelns (1999) reported that about 28% of farmland in Egypt has been affected by the waterlogging and salinization only few decades after the commissioning of the Aswan High Dam.

An FAO (2002) estimate showed that about 10% of the global land area is affected by waterlogging and salinization problems. El-Ashry and Duda (1999) reported that about 30 million ha are severely affected by waterlogging and salinization problems. This area is expected to rise further with the progression of irrigated agriculture because generally agriculture is not associated with conservation and sustainable resource management (Kumar and Singh, 2003; De Fraiture et al., 2010). Abbas et al. (2013) estimated that at global level salinization of soil is increasing at a rate of about 2 million ha per annum. Ghassemi et al. (1995) reported that about seven percent of the earth's continental area, which is equal to nearly one billion ha, is associated with salt problems. Samad et al. (2001) reported that the effects of waterlogging are most widespread in rice–wheat crop rotation in South and Southeast Asia regions. Recently FAO estimated that over 19%, i.e., 45 million ha, of the total 230 million ha irrigated land are salt affected (FAO, 2016). The majority of these affected areas are the result of human activities, i.e., mismanagement of irrigation water.

Waterlogging and salinization problems can be solved by identifying the critical areas responsible for disproportionate amount of the groundwater recharge and to implement best water management practices in the recognized areas (Chowdhury, 1998; Singh, 2013). Generally, waterlogging and salinization problems were studied through the conventional techniques such as numerical simulation, hydro-socio-economic and meteorological analysis, and estimation of waterlogged areas (Hsu et al., 2000; Wang et al., 2006). However, these techniques require lots of data which could not be acquired easily, thus it is difficult to study the waterlogging risk in a region where data observation points are weak. Also these techniques are neither cost effective nor time effective (Singh and Panda, 2012c).

Remote sensing and GIS offer a good alternative to conventional techniques in monitoring and evaluating the extent of waterlogged areas in real time (Albertson and Williamson, 1992; Baker et al., 1993; Cherkauer, 2004; Elhag, 2016). GIS can be defined as a system of capturing, storing, manipulating, analyzing, and displaying spatial information in an efficient manner (Camp and Brown, 1993; Hall and Zidar, 1993; Szilagyi et al., 2003). Data input subsystems, data storage and retrieval subsystem, data manipulation and analysis subsystem, and data reporting subsystem are the general components of GIS software. GIS has progressed as a highly