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Review

Managing the salinization and drainage problems of irrigated areas through remote sensing and GIS techniques

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ABSTRACT

The development of irrigated agriculture is a requirement for feeding the rising world population but without proper drainage provisions, this development can result in irrigation-induced salinization in agricultural areas. The management of salinization and drainage problems at the regional level are considerably hindered due to lack of good quality data because the regional studies entail distributed data, while usual hydrological measurements offer only point data. With the emergence of new geospatial techniques and tools such as GIS and remote sensing, the regional salinization and drainage studies have become easier in recent times. The GIS and remote sensing techniques are vital means and provide a better alternative to the conventional techniques in monitoring and assessment of poor-drainage affected salinized areas. These geospatial techniques present apt solutions to map the degree and severity of drainage-induced land salinization, mainly in large regions. This paper provides an overview of GIS and remote sensing techniques used for the management of salinization and drainage problems of water resources in irrigated areas. The indication of the salinization and drainage problems of water resources along with the importance of the study is presented. The rationale and background of the environmental problems of irrigated areas are provided. The combined applications of geospatial techniques in managing the environmental problems are detailed. Finally, the applications of GIS and remote sensing techniques in various case studies across the globe are discussed and some conclusions are summarized.

1. Introduction

The development of irrigated agriculture is necessary for feeding the rising world population (Xie et al., 2018; Das et al., 2015; Lomba et al., 2017; Singh, 2015a,b) which is likely to reach between 9 and 10 billion in 2050 (United Nations, 2017). Nevertheless, without proper drainage provisions, this development can result in irrigation-induced salinization and rising watertable problems in agricultural areas (Singh and Panda, 2012a,b,c; Singh, 2017). Drainage and salinization problems are prevalent in irrigated areas of the world (Arslan, 2012). Unrelenting irrigation over a large number of years without sufficient drainage facilities resulted in large tracts of irrigated areas becoming infertile (Smedema, 1990). Singh et al. (2016, 2012), Akkaya Aslan and Gundogdu (2007), and Singh (2018, 2014a, 2012) reported that irrigation-induced land salinization has put serious risks to the sustainability of irrigated agriculture. They also stated that salinization and rising watertable problems has enlarged considerably during the last few decades on account of the speedy expansion of large-scale irrigation (Singh, 2011, 2010). Drainage is necessary not only for the removal of water which prevents rising watertable but also for removing the salts which prevent salinization from rootzone. Bos and Boers (1994) stated that land drainage is one of the key inputs to get better yields per unit of farmland.

The management of salinization and drainage problems of irrigated agriculture are considerably hindered due to lack of good quality data (Elhag, 2016). This is mainly serious in dry areas where inspection infrastructure is feeble (Brunner et al., 2007). Regional salinization and drainage studies entail distributed data, while usual hydrological measurements offer only point data (Wondzell et al., 2009). In the lack of necessary widespread data, the regional studies cannot deliver reliable outputs (Kasahara and Hill, 2006). With the emergence of new geospatial techniques and tools such as GIS (geographic information system) and remote sensing, the regional studies have become easier in recent times (Stisen et al., 2011; Dar et al., 2010; Gebreyohannes et al., 2013). Tsihrintzis et al. (1996) and Becker (2006) provided various aspects of the use of geospatial techniques in managing the water resources problems of agricultural lands. Tlapáková et al. (2016) show the benefits of remote sensing techniques for mapping subsurface drainage systems in the Czech Republic. In the past few decades scholars have widely used GIS and remote sensing techniques to solve the drainage and salinization problems of irrigated areas (Zewdu et al., 2015; Muller and van Niekerk, 2016; Oikonomidis et al., 2015; Quan

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et al., 2010). This paper provides an overview of GIS and remote sensing techniques used for the management of salinization and drainage problems of water resources in irrigated areas.

The paper is organized into five sections trailed by references' list. An indication of the salinization and drainage problems of water resources along with the importance of the study is presented in Section 1. Section 2 deals with the rationale and background of the environmental problems in irrigated areas. The combined applications of geospatial techniques in managing the environmental problems are detailed in Section 3. The applications of GIS and remote sensing techniques in various case studies across the globe are discussed in Section 4. Finally, conclusions of the study are summarized in Section 5.

2. Rationale

The poor drainage related salinization and shallow watertable problems of agricultural areas can be solved by spotting the critical areas (Chowdhury, 1998). Usually, these problems were analyzed through the conservative practices such as estimation of salt affected areas, meteorological and hydro-agro-economic analysis, and numerical simulation etc among others (Wang et al., 2006). Nevertheless, these practices entail plenty of data which is difficult to acquire. Therefore, it is complex to analyze the salinization risk in an area where data inspection points are feeble. Also, these practices are neither time-efficient nor cost efficient (Singh, 2016).

The geospatial techniques such as GIS and remote sensing presents apt solutions to map the degree and severity of drainage-induced land salinization, mainly in large regions (Kumar et al., 2015; Chowdary et al., 2008). The geospatial techniques have been extensively utilized to appraise land salinization since the 1960s whereas various coloured aerial photographs were used to map salt-affected areas (Fan et al., 2015). The core of remote sensing is the quantifying and documenting the electromagnetic radiation echoed by the surface of the earth. Huang et al. (2008) and Aslam et al. (2015) stated that these geospatial techniques are useful in the creation of the maps and construction of the record more precisely. These techniques are also helpful in the computation of area statistics more rapidly than the conservative ones (Herzog et al., 2003). Xu et al. (2011), Dwivedi and Sreenivas (2002), Leblanc et al. (2007), Quan et al. (2010) and reported that the use of GIS and remote sensing techniques has been enlarged noticeably in the recent times for the monitoring and detection of poor drainage-related salinized lands in various parts of the world. During the recent past, a number of studies have shown the success of these techniques on managing the problems of land and water resources (e.g., Stisen et al., 2011; Leblanc et al., 2003; Sidhu et al., 1998; Lubczynski and Gurwin, 2005). The GIS and remote sensing are good means in examining the developments of land salinization because of its capacity to capture information in spatial and temporal scales (Tlapáková et al., 2016; Abbas et al., 2013).

The GIS and remote sensing techniques provide a good option to the conservative ones in assessing and monitoring the degree of land degradation due to poor drainage and salinization (Elhag, 2016; Cherkauer, 2004; Singh, 2014b; Lanfear, 1992). Szilagyi et al. (2003) and Hall and Zidar (1993) stated that the GIS can be described as a method of capturing and storing spatial data in a well-organized manner which can be manipulated, analyzed, and presented in a preferred mode for its specific applications. The remote sensing and GIS techniques make it probable to acquire multi-temporal data for changeable settings and spatial domains which is a major constituent to detect and monitor soil salinity (Scudiero et al., 2015).

The common constituents of a GIS software include data storage and retrieval subsystem, data input subsystems, data reporting subsystem, and data manipulation and analysis subsystem (Baker et al., 1993; Gregoretti et al., 2016). Denning (1993) and Vieux (1991) detailed that GIS has advanced as a very classy database organization system to store and compose the large data normally necessary in land and water management. Tsihrintzis et al. (1996) presented a review of the applications of GIS in resources management. The study reported that because of spatial nature of the requisite information, GIS can be employed successfully in managing the resources problems. Later, Becker (2006) presented the various aspects of remote sensing technique for the management of water resources problems. Mandal and Sharma (2001) and Maidment (1993) used GIS and remote sensing techniques for examining and mapping of poor drainage-induced salinized areas. Earlier, a similar approach has been used by Jeton and Smith (1993) and Bhaskar et al. (1992) for managing the water resources problems of irrigated areas with the use of GIS and remote sensing techniques. Naz et al. (2009) stated that field-based methods for the identification of tile drain networks are labor-intensive and thus improbable for use at watershed scales. On the other hand, airborne GIS and remote sensing based methods are swift and offer the potential for spatially-expansive estimates.

3. Combined applications of geospatial techniques

The combined applications of GIS and remote sensing techniques are more useful than their single applications (Gossel et al., 2004). Engman and Gurney (1991) pointed that remote sensing has been extensively used to complement typical geophysical techniques for the management of water and land resources problems. Ramalingam and Santhakumar (2002) stated that the combined use of GIS and remote sensing is an important tool for the meting out and management of large-scale data. The combined GIS and remote sensing approach were used by Mohamed et al. (2013) for the evaluation of various degraded areas in the eastern Nile Delta region of Egypt. Rango (1994) and Duchon and Nicks (1990) presented a detailed report of the hypothesis and applications of remote sensing processes in water resources management. They concluded that the remote sensing allows analysis of the interface between diverse terrestrial components. Later, Gogu et al. (2001) and Vasanthakumaran et al. (2002) reported that the combined applications of GIS and remote sensing is a good tool for the investigation of large agro-hydro-climatic data. They also stated that the combined applications of the geospatial techniques are additionally good for the modeling of composite surface and subsurface transport and flow processes under unsaturated and saturated environments.

The combined GIS and remote sensing techniques were used by Malla (1991) for the management of watershed in the Kiseki Sub-watershed, Nepal. The study reported that the geospatial techniques are rather fast, economical, and simple to employ and they have the potential to analyze the biophysical resources of the watershed. Bastiaanssen et al. (2000) and Crow et al. (2009) stated that the geospatial techniques, with various accuracy levels, have been proficient to offer information on the area under irrigation, type of crops, water requirement of crops, land cover and land use, and the degree of land salinization. Meijerink (2000) reported the use of remote sensing in the analysis of groundwater recharge and concluded that these techniques extensively sustain the conservative evaluation and simulation techniques. Later, the ability of GIS technique in mathematical simulation for water resources was shown by Chenini and Mammou (2010). The study combined a GIS software with the simulation model and applied the same in an area of central Tunisia. Tripathi et al. (2003) performed the terrain attribute-based prioritization of watershed to classify and describe the units of territory for providing the mapping symbols. Li et al. (2009) stated that the content of spatial data is the most under-utilized potency of geospatial techniques.

The remote sensing algorithms were used by Bastiaanssen (1998) for the indicators-based performance evaluation of an irrigation system. The approach was somewhat similar to one which was used by Menenti et al. (1989) for the same purpose. Rochester et al. (1996) stated that due to its flexible design the GIS technique helps to investigate extensive hydro-geological progressions and to assess the impact on water quality and land organization measures. Gundogdu and Guney (2007)