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Review

Big GIS analytics framework for agriculture supply chains: A literature review identifying the current trends and future perspectives

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ABSTRACT

The world population is estimated to reach nine billion by 2050. Many challenges are adding pressure on the current agriculture supply chains that include shrinking land sizes, ever increasing demand for natural resources and environmental issues. The agriculture systems need a major transformation from the traditional practices to precision agriculture or smart farming practices to overcome these challenges. Geographic information system (GIS) is one such technology that pushes the current methods to precision agriculture. In this paper, we present a systematic literature review (SLR) of 120 research papers on various applications of big GIS analytics (BGA) in agriculture. The selected papers are classified into two broad categories; the level of analytics and GIS applications in agriculture. The GIS applications viz., land suitability, site search and selection, resource allocation, impact assessment, land allocation, and knowledge-based systems are considered in this study. The outcome of this study is a proposed BGA framework for agriculture supply chain. This framework identifies big data analytics to play a significant role in improving the quality of GIS application in agriculture and provides the researchers, practitioners, and policymakers with guidelines on the successful management of big GIS data for improved agricultural productivity.

1. Introduction

As defined in the Agriculture Act, 1947, agriculture includes horticulture, fruit growing, seed growing, livestock breeding and keeping, and dairy farming. Agriculture also consists of the use of land for grazing, and woodlands for agricultural purposes (Bhavikatti, 2005). The main aim of agriculture is to maximize the land utilization and increase the profits. The modern technologies that contribute towards the improvement of agriculture productivity are focused on developing new breeds of the crop through hybridization offering improved resistance to pests and diseases, low response time to the fertilizers and low water consumption. With the world population expected to reach nine billion by 2050 (Gilpin, 2015) there will be an increased demand for food resources (Godfray et al., 2010). Majority of the people (one in seven) suffer from a deficiency of protein and energy and other form of micronutrient malnourishment (FAO, 2009). The increasing gap in demand and supply of food presents a set of new intersecting challenges adding pressure on the agriculture supply chain (Evans, 2009). The food producers are competing for land, water, and energy resources experiencing the need to restrict the adverse effects of food production on the environment (Tilman et al., 2001; Millennium Ecosystem Assessment, 2005). These changes have pushed the producers to move from the conventional agriculture (CA) to precision agriculture (PA). PA was introduced in the late 1990s with John Deere fitting their tractors and machinery with GPS sensors for information management. With the arrival of the Internet of Things (IoT) in the technological landscape, all devices are now connected and interact with each other (smart devices) via wireless network infrastructure (Wolfert et al., 2017; Porter and Heppelmann, 2014). PA is an extension of this development and is the primary driving force for big data analytics (BDA) in agriculture (Wolfert et al., 2017; Lesser, 2014; Poppe et al., 2015). The primary emphasis of PA is on the collection, management, and utilization of data to make decisions (Pham and Stack, 2018). PA requires a host of technologies which work in synchronization to enable data collection and analysis (CEMA, n.d., 2017). As shown in Fig. 1, these technologies include Geographic Positioning System (GPS), Geographic Information System (GIS), Remote Sensing (RS), Geo-mapping, sensors, electronic communication devices, and Variable Rate Technology (VRT).

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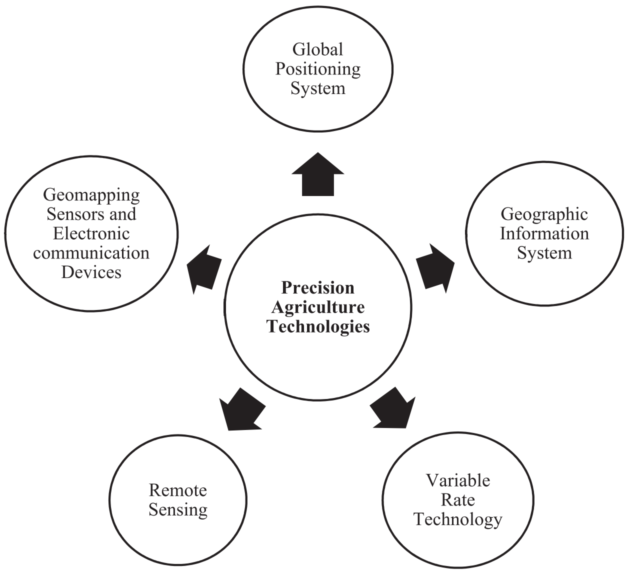

Fig. 1. Applications of GIS in precision agriculture.

1.1. Geographic information system (GIS)

GIS deals with spatial data and visualizes the collected information with patterns and relationships using computer-based tools. GIS includes the following components.

- Storage of spatial data in digital form.
- Management and integration of spatial data collected from different sources into the GIS system.
- Retrieval and conversion of the spatial data in the required formats.
- Performing data analytics to convert data into useful information.
- Developing different models based on the information.
- Display of information model and decision making.

GIS technology has grown exponentially over the past decades and today is considered as potential geographic based IT processing tool for spatial data analysis and management (Malczewski, 2006). GIS plays a significant role in managing the natural resources, environmental protection, regional and urban planning and development, and management of utilities (Jankowski 1995; Abdelrahman et al., 2016; Montgomery et al., 2016). GIS is transforming the agriculture sector in incredible ways. The hyperspectral and multispectral images obtained through the geospatial data is found to be very useful for analyzing parameters such as crop health and soil moisture. The GIS supports high level of decision making for effective management of fertilizer and pesticides, stress mapping, and irrigation (Barnes and Baker, 2000; Barroso et al., 2008; Hinzman et al., 1986; Lelong et al., 1998; Pal and Mather, 2003; Singh et al., 2007; Tilling et al., 2007). Bio-physical attributes of crops and soils are used with GIS and RS technologies for radical improvement in the agricultural productivity (Liaghat and Balasundram, 2010).

Whilst there has been a significant body of research that focuses on GIS applications in agriculture, there is relatively less emphasis on the evaluation of factors such as land suitability, site search and selection, resource allocation, impact assessment, knowledge-based systems and GIS analytics (Li and Yan, 2012; Tayyebi et al., 2016; Ines et al., 2002; Wei et al., 2005; McKinion et al., 2010; Wachowiak et al., 2017; Neufeldt et al., 2006). Further, the spatial data sets that exceed the traditional computing capacity, referred to as big geospatial data is receiving high attention from the researchers (Lee and Kang, 2015). With the exponential increase in the amount of big geospatial data, the challenges for managing and analyzing the big data has also increased. Geospatial data represents a significant portion of big data in agriculture supply chains, with its size proliferating at least by twenty percent every year (Lee and Kang, 2015). There have been many studies concentrating on the applications of BDA in operations and supply chain management in different industries (Wang et al., 2016; Gandomi and Haider, 2015; Erevelles et al., 2016; Raghupathi and Raghupathi, 2014). However, the applications of big GIS analytics (BGA) in agriculture hasn't received much attention.

The present review aims to draw on recent literature to examine the role of GIS applications in agriculture and identify the future perspectives on integrating the big data with GIS. While previous studies have focused on specific applications of GIS in agriculture, this paper holistically covers all the major applications and additionally uses the level of GIS analytics (*predictive, descriptive and prescriptive*) for classification of the selected papers. The outcome of the review is development of the BGA framework for agriculture.

The remaining of the paper is organized as follows. Section 2 presents the review methodology. Section 3 discusses the findings of the review. A BGA framework is proposed in Section 4. Section 5 discusses the future perspectives, and Section 6 presents the conclusions and limitations of the study.

2. Review methodology

A systematic literature review (SLR) is used to examine the various GIS analytics applications in agriculture. The SLR was carried as per the guidelines given by Tranfield et al. (2003) in three stages:

i. Review planning
ii. Conducting the review
iii. Findings and dissemination.

The SLR stages are briefly discussed below.

2.1. Review planning

The primary objective of this study was to examine the GIS applications in agriculture and identify future research perspectives. Therefore the SLR was designed to include only those research papers that addressed the different applications of GIS in agriculture. The procedure used to select the papers for the final review is discussed below.

2.2. Conducting the review

2.2.1. Selection of papers

Only research articles from refereed journals available on the ISI Web of Science (WoS) database were selected for analysis. Based on the focus of the present study the search keywords included: GIS in agriculture, GIS mapping in agriculture, GIS applications in agriculture. The time frame involved for the literature review covers the studies published during 2000–2018. The initial search returned 2369 articles. Only articles published in academic journals were selected reducing the number of articles to 1689. A further refinement based on reading the abstract led to a drop in the number of articles to 450. The number of articles was further reduced by using the keywords "crop yield estimates," "soil amendment analysis," "erosion identification and remediation," "irrigated landscape mapping," "agricultural mapping," "monitoring of soil and irrigation," "crop mapping," and "agricultural resources." The use of these keywords also set the scope for the literature review in the present study. The final inclusion criteria included selecting the research paper from the journals which has published minimum three articles relevant to the focus of the review. Total 120 research articles were selected for the final review.

2.2.2. Classification framework

In the previous studies on GIS in agriculture, applications in land