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Effect of climate change on land suitability for surface irrigation and irrigation potential of the shallow groundwater in Ghana

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ABSTRACT

Estimating the potential land resources suitable for irrigation and evaluating the possible impact of climate change on land suitability is essential for planning a sustainable agricultural system. This study applied a GIS-based Multi-Criteria Evaluation (MCE) technique to evaluate the suitability of land for irrigation in Ghana for a baseline period (1990 to 2010) and future time horizons 2050s (2041 to 2060) and 2070s (2061 to 2080). Key factors considered to evaluate the suitability of the land for irrigation include biophysical features (such as climate, land use, soil, and slope) and socioeconomic factors (such as proximity to roads and population density). These factors were weighted using a pairwise comparison matrix then reclassified and overlaid on a 30 m grid to estimate the irrigation potential of the country. Groundwater data from the British Geological Survey (BGS) were superimposed onto the land suitability map layer to evaluate the irrigation potential and the accessibility of shallow groundwater with simple water lifting technologies. Downscaled and bias-corrected future climate data from HadGEM2-ES under Representative Concentration Pathways (RCP) 4.5 emission scenario were used to represent the future climate horizon. Due to climate change, on average, rainfall will increase by 15 mm and 20 mm from the baseline period in the 2050s and 2070s, respectively. The average temperature shows a consistent increase in the majority of Ghana and a higher rate of increase is expected in the 2070s. Consequently, the rising temperature will increase the potential evapotranspiration by 6.0% and 7.6% in the 2050s and 2070s, respectively. The suitability analysis indicates that approximately 9% of the country is suitable for surface irrigation under the baseline period. A large portion of the potential land is located in the southwestern part of the country. The potential suitable land has an average groundwater access of 12 m from the surface with an average borehole potential yield of 2.5 L/second, which makes it favorable for utilization of simple water lifting technologies. Due to climate change, 9.5% of the suitable land will become unfavorable for irrigation in 2050s, and it is expected to reach 17% in 2070s.

1. Introduction

Agriculture is critical to the economy of Ghana, which employs more than 50% of the population on a formal or informal basis and contributing 25% of the gross domestic production (GDP) and export earnings (Forkuor et al., 2013; Heintz, 2005). Agriculture has grown consistently by more than 5% annually for the last 25 years (Mendes et al., 2014). Despite this consistent growth, the country remains a major net importer of agricultural food products (Ashitey and Rondon, 2012) due to heavy reliance on rainfed production and drought vulnerability (Antwi-Agyei et al., 2012; Laube et al., 2012). Less than 2% of the total cultivatable area in Ghana is estimated to be under irrigated production (Gumma and Pavelic, 2013; Mendes et al., 2014; Namara et al., 2011a, b). Moreover, the area under small-scale irrigation by individual farmers in Ghana has been estimated to be about five times that under formal private or public communal irrigation schemes (Dittoh et al., 2013). The direction of recent government policy direction is to increase irrigated agriculture to enhance productivity (MOFA, 2014) and ensure food security. Hence, assessing the suitability of areas for irrigation will be critically important for planning and

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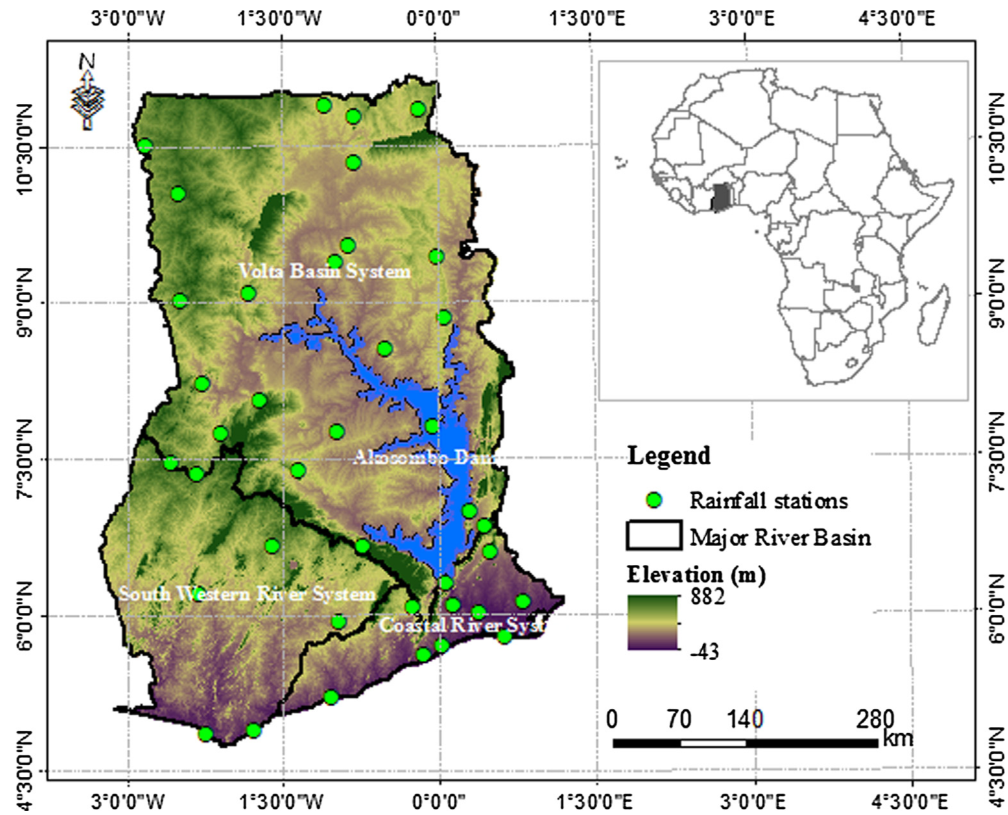

Fig. 1. Spatial distribution of rainfall gauging stations in Ghana with the three major river basins, and a 30 m-resolution digital elevation model as a background.

implementation. Some studies suggest that irrigation development, including agricultural reformulation in terms of policy, technology, and management practices, could contribute to greater food security and increase overall economic growth (Giordano and de Fraiture, 2014; Giordano et al., 2012; Worqlul et al., 2018a). This paper, therefore, explores the potential for implementing irrigated agriculture in Ghana, particularly using shallow groundwater. Ghana appears to have abundant water resources to increase irrigation rainwater harvesting, surface storage and groundwater (Ofosu, 2011). However, rainfall is unevenly distributed across the country, both spatially and seasonally (Adimassu et al., 2016; Rademacher-Schulz et al., 2014). Mendes et al. (2014) indicated that if managed well, the country's surface runoff and groundwater could meet most domestic and irrigation requirements. However, irrigation using surface water is limited due to the capital investment required for channeling the surface water to the potential irrigable areas over long distances (Obuobie et al., 2013). Widespread groundwater availability as a buffer against drought and climate change variability could potentially transform the agricultural sector in Ghana (Obuobie et al., 2012). However, there are only limited studies that provide a robust estimate of the potential suitable land for irrigation using groundwater in Ghana. Moreover, climate change has become one of the biggest challenges of this century. The threat of climate change is multidimensional; it affects agriculture and food security (Nelson et al., 2009; Rosenzweig and Parry, 1994; Schmidhuber and Tubiello, 2007), human health, livestock production and marine ecosystem (Hoegh-Guldberg and Bruno, 2010; McMichael et al., 2007; Patz et al., 2005) and the environment (Galbraith et al., 2002; Green et al., 2011). Climate change will have a significant effect on the agriculture production of sub-Saharan countries due to higher seasonal rainfall variability and lower water availability. A temperature increase and rainfall reduction and higher variability will make many agricultural areas less productive or even completely unsuitable for agriculture (Mendelsohn and Dinar, 1999). Understanding the effect of climate change on land use suitability will help the effort of developing mechanisms to put in place to ensure resilience to reduce the vulnerability facing the nation in the future.

This study, therefore, uses a GIS-based Multi-Criteria Evaluation (MCE) technique to identify the spatial distribution of the land that is potentially suitable for shallow groundwater irrigation under both current and future climate conditions. The MCE technique identifies the potential suitable land by considering multiple factors affecting the suitability of a certain land area for irrigation. In MCE, these factors affecting are mapped, weighted to determine their relative impact, and then combined to develop a single indexed output. MCE has been applied to land suitability analysis for irrigation (Assefa et al., 2018; Mustafa et al., 2011; Pereira and Duckstein, 1993; Prakash, 2003; Zhang et al., 2015), and also in other field of studies including site selection for convenience store location (Kuo et al., 2002), urban land use planning (Mosadeghi et al., 2015), hospital site selection (Vahidnia et al., 2009), thermal power plant site selection (Choudhary and Shankar, 2012), solid waste disposal site identification (Şener et al., 2010; Sumathi et al., 2008; Wang et al., 2009), mapping of erosion-prone areas (Assefa et al., 2015; Pal, 2016), and financial decision-making (Steuer and Na, 2003). This study will be the first of its kind to provide spatially explicit potential suitable land for irrigated agriculture for the current and future time horizons. The findings may provide valuable information to researchers, decision makers, practitioners, and investors to prioritize irrigated agriculture scaling in Ghana. The paper may also provide insight into understanding the impact of climate change on irrigated agriculture, and thereby devise policies to mitigate its impacts.

2. Materials and methods

2.1. Study area

This study was carried out for the entire Republic of Ghana, located along the Gulf of Guinea and the Atlantic Ocean in West Africa.

Geographically, the country is located between 3°33′ W to 1 °30′ E and 4°32′ to 11°10′ N (Fig. 1). The elevation ranges from −43 to 882 m amsl (above mean sea level). The country has a tropical humid climate with high seasonal and annual rainfall variability (Opoku-Ankomah and Cordery, 1994; Swaine, 1996). Generally, the climate in Ghana is tropical with distinct wet and dry seasons. The annual average rainfall from 1990 to 2010 varied between 650 and 1900 mm. The southwestern coast of the country receives the highest rainfall above 1400 mm/year, while the northern part of the country is the driest region receiving less than 800 mm/year.

2.2. Methodology

The land suitability study was accomplished using a multi-criteria evaluation technique for baseline period using historical climate data (1990 to 2010) and projected time horizons 2050s (2041 to 2060) and 2070s (2061 to 2080). In MCE, the major factors affecting the land suitability for agriculture were mapped on a GIS environment to develop a single-indexed output (Ceballos-Silva and Lopez-Blanco, 2003; Chen et al., 2010; Feizizadeh and Blaschke, 2013; Pohekar and Ramachandran, 2004; Worqlul et al., 2015). The major factors determining the land suitability for irrigation were identified from the literature and expert consultation (Akıncı et al., 2013; Chen et al., 2010; Mendas and Delali, 2012; Worqlul et al., 2015). The biophysical factors included were climate (baseline, 2050s, and 2070s), soil, land use, and topography. The socio-economic factors included were market access represented by proximity to a road and population density. Table 1 presents the major factors considered to identify the potential land suitable for irrigation in Ghana, as well as the data sources with their respective spatial resolutions. The general framework of the land suitability analysis is presented in Fig. 2.

The data were collected in vector and raster formats. The factors were weighted using a pairwise comparison matrix (Saaty, 1977), and the relative importance of the factors was computed by normalizing the eigenvector of the factors by their cumulative sum. The overall weights of the factors were distributed to the different levels of suitability classes by an equal interval ranging technique. In this technique, the class break is determined by the weight of the factor divided by the number of classes (Alsahli and Al-Harbi, 2017; Nandi and Shakoor, 2010). The reclassified and weighted factors were combined with a weighted overlay analysis to calculate the preliminary land suitability map. A constraint map, which contains land use types that limit the suitability of land for surface irrigation (such as water bodies, wetlands, urban areas, forest, and protected areas) was developed to exclude the permanently non-suitable areas. The most optimal suitable land for irrigation was identified by applying a user-defined threshold number, which was greater than or equal to 80% of the suitability index. That optimal suitable land was overlaid to a GIS layer of groundwater spatial data collected from the British Geological Survey (BGS, MacDonald et al., 2012) to evaluate the potential and accessibility of the groundwater for irrigation. The BGS data consists of borehole potential yield and depth to groundwater table.

2.2.1. Biophysical factors

The biophysical factors determine if irrigation is possible in a particular location or not; for example, the climate and the landscape must be convenient for practicing irrigation. Therefore, in this study, climate, land use, soil, and slope were considered the most important determining factors for irrigation suitability. A detailed description of the biophysical factors used to evaluate the suitability of land areas for irrigation in Ghana is discussed below:

2.2.1.1. Climate factor for the baseline and future time horizons. The climate of the study area was represented by long-term rainfall and potential evapotranspiration for baseline and future time horizons. For the baseline period (1990 to 2010), rainfall data from 64 weather stations (Fig. 1) distributed across Ghana were obtained from the Ghana Meteorological Agency (GMA). The daily rainfall data aggregated to annual average were compared with station elevation to understand the relationship between rainfall and elevation. Overall, the estimated elevation-rainfall relationship indicated a weak linear association with a coefficient of determination of 0.1. Because of this poor association, elevation was not used as an auxiliary variable for the rainfall interpolation (Goovaerts, 2000). Instead, the Inverse Distance Weighting (IDW) interpolation method was used to interpolate the station rainfall into areal rainfall. The IDW method is well-established and has demonstrated outstanding performances in estimating spatial rainfall in different regions across the world (Basistha et al., 2008; Chen and Liu, 2012; Tomczak, 1998). Fig. 3a shows the IDW interpolated annual rainfall of Ghana of the baseline period.

The potential evapotranspiration data for the baseline period was obtained from the improved MODIS global evapotranspiration (ET) product (Mu et al., 2011). The improved MODIS ET data were developed based on MODIS and global metrological data (Mu et al., 2011). The improved MODIS global ET data were validated in a diverse range of ecosystems across five continents (Mu et al., 2011). The validation data includes 46 eddy-flux towers and showed a favorable agreement (Mu et al., 2013; Mustafa et al., 2011). The data has been widely applied for a global and regional analysis (Kim et al., 2012; Ramoelo et al., 2014; Ruhoff et al., 2013) and carbon budgets (Yang et al., 2014). The MODIS ET dataset covers for the period from 2000 to 2010 at 8 day interval with a spatial resolution of 1 km. The long-term average annual potential evapotranspiration was estimated by aggregating the 8 day MODIS ET (Fig. 3b).

Climate data of the future time horizons was represented with the downscaled and bias-corrected Global Circulation Models (GCMs) from Coupled Model Inter-comparison Project phase 5 (CMIP5) (Fick Stephen and Hijmans Robert, 2017). The projected climate data used was the Representative Concentration Pathway (RCP) 4.5, which is considered “moderately optimistic” pathways (Hijmans et al., 2005).

Table 1
Factors included in the land suitability analysis including their source and spatial resolution.

Data	Source	Spatial resolution (m)
Land use	Global Land Cover Datasets (GlobeLand30)	30
Soil	Africa Soil Information Service (AfSIS), 2015	250
Digital Elevation Model (DEM)	Enhanced Shuttle Land Elevation Data from United States Geological Survey (USGS), 2000 released in 2015	30
Population density	Global Gridded Population Database, 2015	1000
Road network	Digital Chart of the World (DCW), 2006	–
MODIS potential evaporation (mm)	MOD16 Global Terrestrial Evapotranspiration Data Set (2000 – 2010)	1000
Rainfall (mm/year)	Ghana Meteorological Agency (GMA) from 1990 to 2010	–
Groundwater depth (m)	British Geological Survey, 2012	5000
Potential borehole yield (l/s)	British Geological Survey, 2012	5000
Groundwater storage (mm)	British Geological Survey, 2012	5000
Future time horizon rainfall	Coupled Model Inter-comparison Project phase 5 (CMIP5) from 2041 to 2060 (2050s).	1000
Future time horizon temperature	Coupled Model Inter-comparison Project phase 5 (CMIP5) from 2061 to 2080 (2070s).	1000

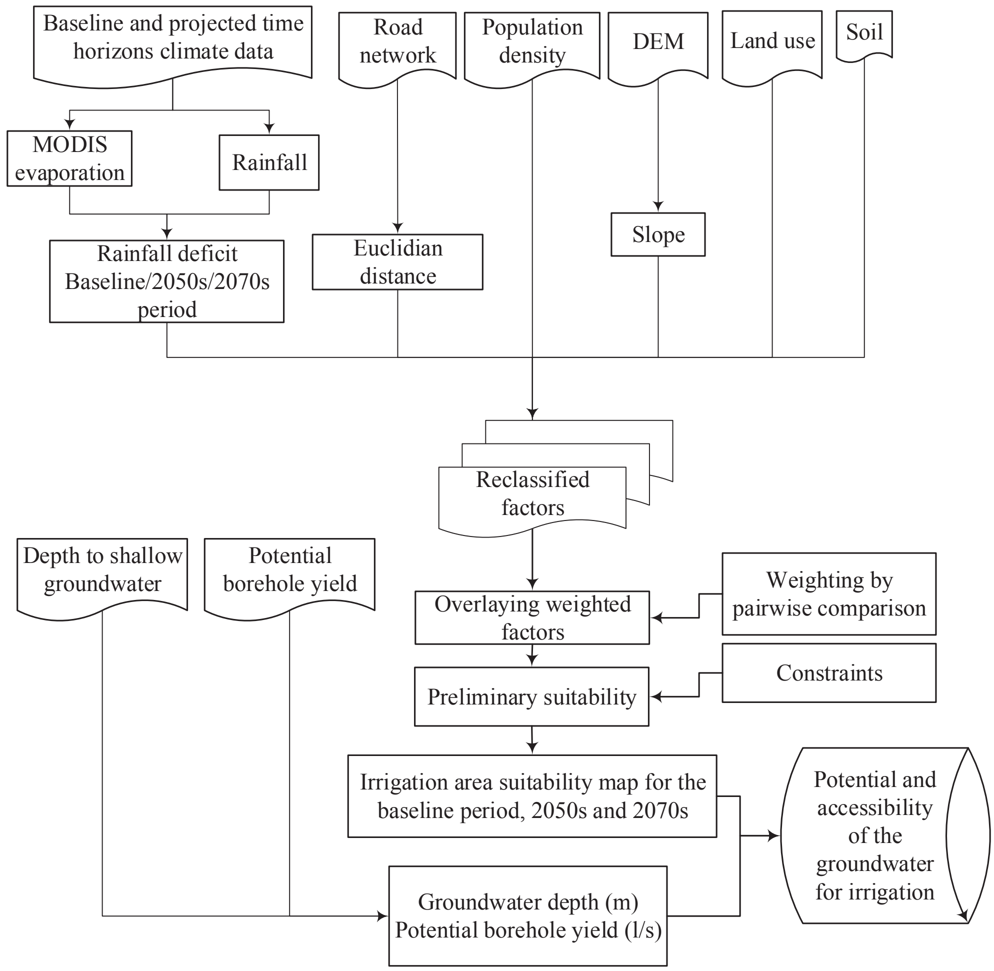

Fig. 2. Schematic diagram of potential irrigable area mapping for the baseline period and future time horizons (2050s and 2070s) and groundwater resource assessment.

The downscaled climate data includes rainfall and minimum and maximum temperature at a spatial resolution of 1 km.

The projected daily rainfall data were aggregated to determine the annual average rainfall. Projected temperature data were used to project the baseline of MODIS potential evapotranspiration into the future time horizons. Temperature is one of the major factors affecting the rate of evapotranspiration and it has a direct linear relationship (Hargreaves and Samani, 1985; Trajkovic, 2005; Xu and Singh, 2001). Due to this, there are various popular temperature-based potential evapotranspiration methods (Xu and Singh, 2001). The change in temperature between the baseline period and future time horizons was used to project the baseline MODIS evapotranspiration into the future. The relationship developed between change in temperature and evapotranspiration for a synthetic scenario using the Penman-Monteith (Penman, 1948) was used to determine evapotranspiration in the future time horizons. The method is briefly discussed under Appendix-1.

2.2.1.2. Land use factor. Land use data of Ghana were collected from GlobeLand30 (GL). The data were developed by the National Geomatics Center of China (NGCC) and donated by the Chinese government to the United Nations as a contribution towards the global sustainable development and combating climate change (Jun et al., 2014). The GL data covers the Earth between the latitude of 80° N and 80° S and developed by integrating satellite images from Landsat Thematic Mapper (TM), Enhanced TM plus (ETM+) and Chinese Environmental and Disaster (HJ-1) (Brovelli et al., 2015). The data is available for 2000 and 2010 and it comprises ten land use groups with a spatial resolution of 30 m.

This study used the 2010 land use data to identify the potential land suitable for irrigation in Ghana. The land use data indicated that the largest proportion of the country is coved with grassland (36%), followed by forest (32%), and shrubland (18%) (Fig. 3c). Agricultural land covers approximately 9% of the country, the major crops grown in Ghana includes cassava, peanut, maize, and legumes. Waterbodies occupy approximately 3.3% of the country. The remaining land use groups were agricultural forest, urban areas, and wetlands.

2.2.1.3. Soil factor. Soil is one of the major factors that determine the suitability of land for irrigation. Soil controls the partitioning of rainfall/irrigation into infiltration and runoff, limits evaporation, and provides nutrients to the plant (Delwart et al., 2008; Kim and van Zyl, 2009). For this study, soil data such as soil texture, organic carbon content, drainage class, and soil depth were combined into a single soil suitability index using the modified Storie Index (SI, O'Geen, 2008; Storie, 1978). The soil data of Ghana were obtained from the Africa Soil Information System (AfSIS, Vågen et al., 2010). The AfSIS soil data has a spatial resolution of 250 m and comes with six layers (0–5 cm, 5–15 cm, 15–30 cm, 30–60 cm, 60–100 cm, and 100–200 cm); each layer includes soil texture, organic carbon content and drainage class. The soil texture was classified using the USDA soil classification, resulting to eight soil classes. Majority of the country is covered by sandy clay loam (49%) and silt loam (36%) (Fig. 3d).

2.2.1.4. Slope factor. Slope plays a major role in determining the

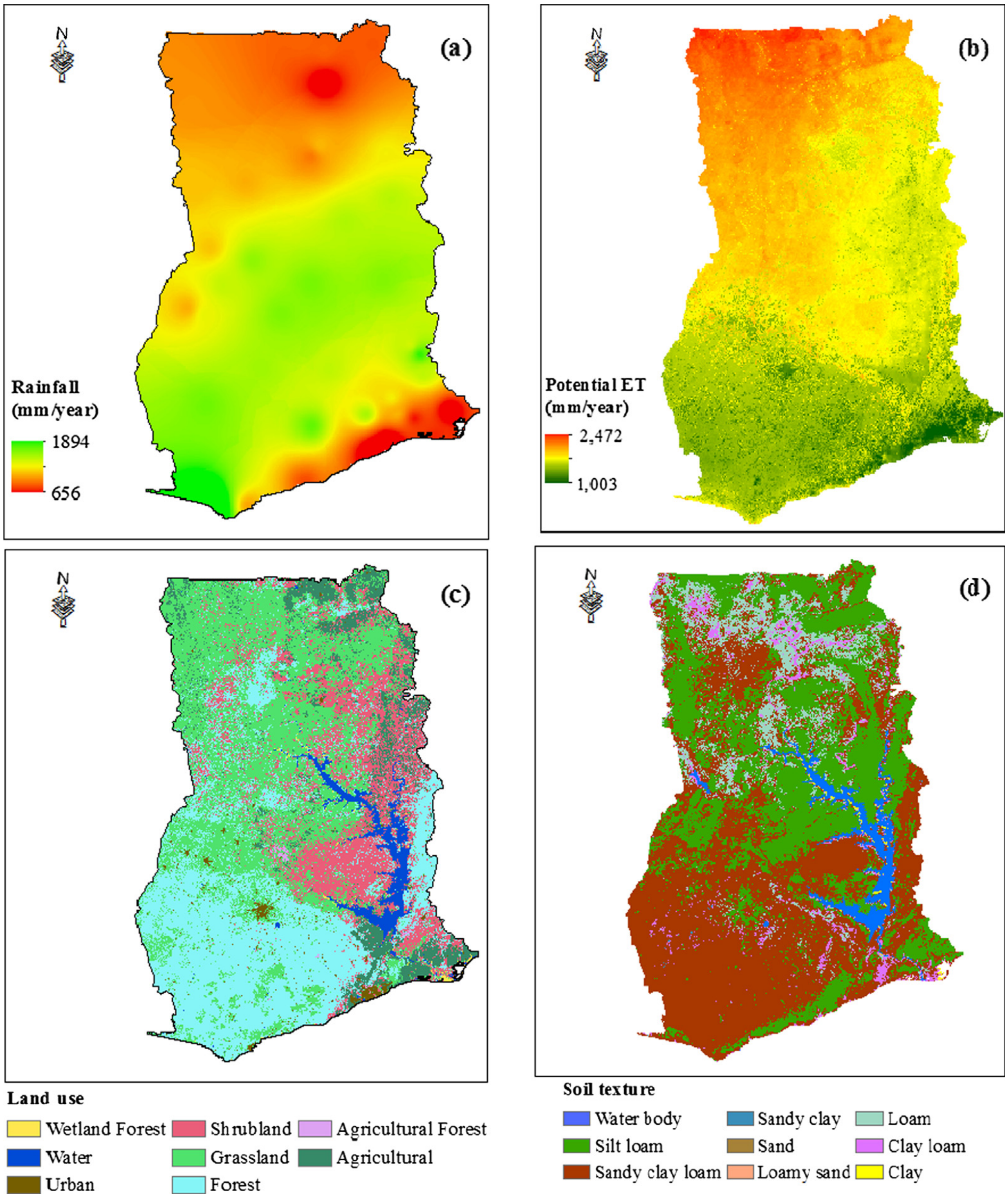

Fig. 3. Factors used to assess the suitability of a land for surface irrigation in Ghana. (a) long-term annual average rainfall (mm) for the period 1990 to 2010, (b) long-term average potential evapotranspiration (mm) for the period 2000 to 2010, (c) land use, d) soil texture.

suitability of land for irrigation by affecting land preparation and irrigation efficiency, especially in surface irrigation. The slope was calculated using a digital elevation model (DEM) which has a spatial resolution of 30 m. The average slope of the country is approximately 6.5%, and approximately 22% of the country has a slope of less than 2%, which is considered as highly suitable for surface irrigation (Fig. 4a).

2.2.2. Socioeconomic factors

The success of irrigation adaptation will depend on access to both agricultural inputs and market for selling agricultural products (Worqlul et al., 2017; You et al., 2011). This study determined market access using population density and proximity to a paved road network. The population density of 2015 was obtained from the Global Gridded Population Database available at the Center for International Earth Science Network (CIESIN) and International Center for Tropical Agriculture (CIAT), Version 4 (GPWv4) (CIESIN, 2016; Doxsey-Whitfield et al., 2015). The global population density was developed by integrating national population data and housing censuses at the administrative level. The population density map of Ghana indicated the highest population density (> 10,000 people/km^2) in the Accra metropolitan areas of the Greater Accra Region, and in the Kumasi metropolitan areas in the Ashanti Region (Fig. 4b).

Road network data collected from the Digital Chart of the World for the year 2006 were used to determine the proximity to a paved road. The distance of a certain land area from the paved road was calculated at 30 m resolution using Euclidean distance (Fig. 4c). The analysis indicated that the average distance of a certain area from a paved road in Ghana is approximately 17 km, while the farthest point is approximately 88 km away.

2.2.3. Groundwater potential

The groundwater data were obtained from British Geological Survey (BGS) and includes borehole potential yield (l/s) and depth to groundwater (m), with a spatial resolution of 5 km (MacDonald et al., 2012). The BGS potential borehole yield was compared with observed

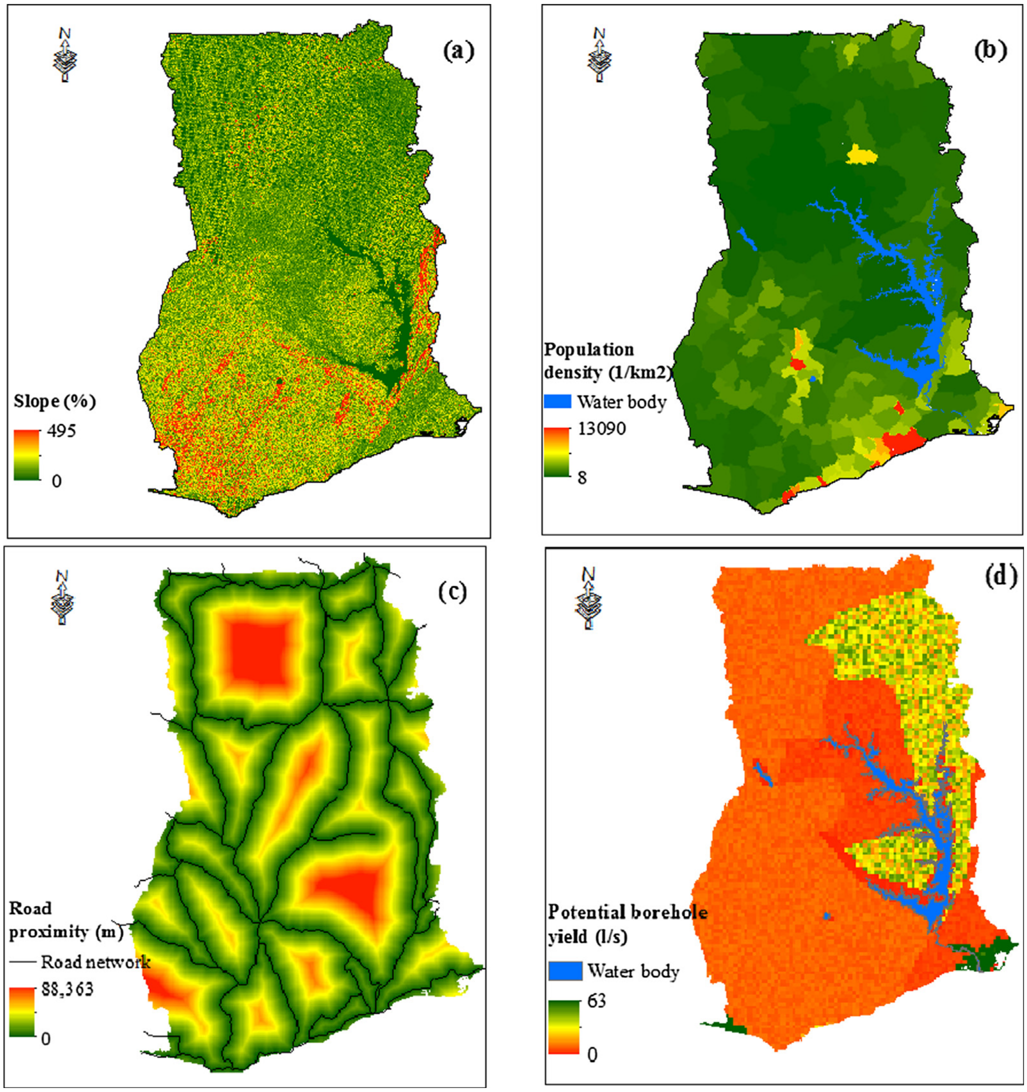

Fig. 4. Factors used to assess the suitability of land for surface irrigation in Ghana. (a) slope (%), (b) population density (per km^2), (c) distance to major paved roads (km) and d) potential borehole yield (l/s).

groundwater yield in the central part of Ethiopia obtained from the Ethiopian Agricultural Transformation Agency (Worqlul et al., 2017). The result indicated that the BGS groundwater potential yield matched well with the observations from ATA. The groundwater data from the BGS were used to identify the potential of the groundwater to irrigate the potential suitable land using simple water lifting technologies. The technologies considered included human, animal, diesel or solar-powered pumps with a maximum operating depth of 25 m and pumping capacity of 0.6 l/s (Assefa et al., 2018). Fig. 4d presents the borehole potential yield.

2.2.4. Weighting of factors

The factors identified for estimating the suitability of the land were weighted using a pairwise comparison technique (Saaty, 1977), which helped to prepare the importance comparison matrix. In the comparison matrix, the highest value corresponds to the absolute importance and the lowest value is the reciprocal indicating absolute triviality inserted at the transpose position of the matrix (Saaty and Vargas, 1991; Worqlul et al., 2015; Worqlul et al., 2017). The relative importance (weights of the factors) were computed by normalizing the eigenvector of the factors by the cumulative sum. The consistency of the pair-wise comparison was evaluated by employing consistency ration (CR, Franek and Kresta, 2014). The CR will evaluate the likelihood of whether the factor weights were randomly assigned or not. For a consistent pairwise comparison, Saaty (1980) suggested that a CR value should not be higher than 0.1, otherwise, the comparison matrix should be revised.

2.2.5. Classification of factors and preliminary suitability

The data collected for the suitability analysis were obtained in two different formats. The continuous geographic phenomena such as soil, land use, population density, elevation, and potential evapotranspiration were in a grid format, while other discrete geographic phenomena such as rainfall and road network were obtained in vector format. The approach in Worqlul et al. (2017) was followed to reclassify the factors. The land use map of Ghana has eight classes (Fig. 3c), and these were reclassified into four levels of suitability according to FAO's recommendation (FAO, 1976; FAO, 1985; FAO, 1989; Walker, 1989). Table 2 presents the FAO framework of land suitability classification. The agricultural land was classified as highly suitable (class S1); grassland, which requires land clearing and leveling was classified as moderately suitable (S2); shrubland, which requires higher initial investment for land preparation was classified as marginally suitable (S3); and forest, water, urban and wetland were classified as not suitable (S4) since they provide other ecosystem services and/or are inconvenient for practicing irrigation.

The soil properties indicating the water holding capacity of the soil

Table 2
Framework of land suitability classification of FAO (FAO, 1976; Worqlul et al., 2015){Worqlul, 2015 #80;FAO, 1976 #137}.

Class	Land Description
Class S1: Highly suitable	Land without significant limitations. This land is the best possible and does not reduce productivity or require increased inputs.
Class S2: Moderately suitable	Land that is clearly suitable but has limitations that either reduce productivity or require an increase of inputs to sustain productivity compared with those needed on S1 land.
Class S3: Marginally suitable	Land with limitations so severe that benefits are reduced and/or the inputs required to sustain production need to be increased so that this cost is only marginally justified.
Class S4 (N1): Currently not suitable	Land that cannot support the particular land use on a sustained basis or land on which benefits do not justify inputs.

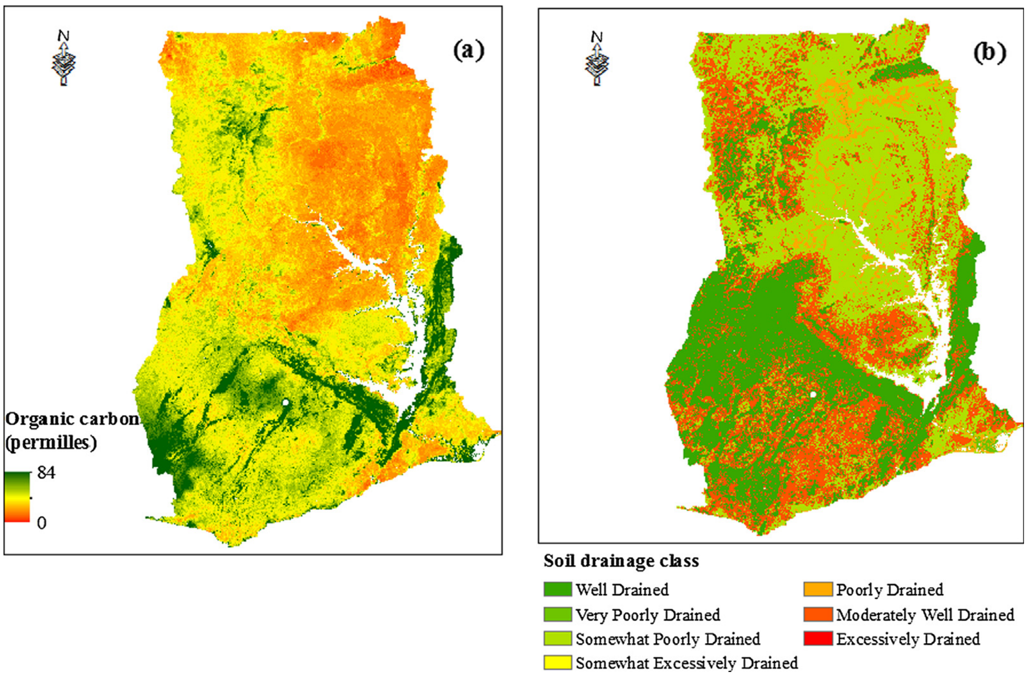

Fig. 5. Factors used to assess the soil suitability for irrigation using Storie Index (SI). (a) organic carbon content (permilles), and (b) soil drainage class.

such as texture, drainage, depth, and organic carbon content were combined to a single soil suitability index called Storie Index (SI, O'Geen, 2008; Storie, 1978). Approximately half of the soil textures in Ghana are composed of silt loam, loam, and clay loam, which has a very high water holding capacity (Fig. 3d). Organic carbon has an important role in physical, biological and chemical properties of the soil, influencing nutrient holding capacity, nutrient turnover, and soil stability (Krull et al., 2004). The organic carbon content of the soil in Ghana varies between zero and 84 permilles, with an average value of 20 permilles. The southern part of the country is dominated by forest cover and is rich in organic carbon, whereas the northern part of the country, which is driest, showed a lower organic carbon content (Fig. 5a). The soil depth varied from zero to 200 cm with an average depth of 180 cm. The soil drainage collected from AfSIS fits into seven classes, the largest three classes were “somewhat poorly drained” (38%), “well drained” (29%), and “moderately well drained” (28%) (Fig. 5b). The computed SI indicates values ranging from 1 (low suitable) to 8 (highest suitable), which were classified into eight suitability classes applying an equal interval ranging technique.

The percent slope map computed from a 30 m resolution DEM (Fig. 4a) was classified into five levels of suitability classes. These levels were 0 to 2%, 2 to 8%, 8 to 12%, 12 to 20% and above 30% which were denoted as highly, moderately, marginally, low and not suitable, respectively. The major paved road networks interpolated with Euclidean distance were reclassified into eight classes of suitability using an equal interval ranging technique. With the maximum distance in Ghana from a paved road being approximately 88 km, road proximity was divided into eight classes. The population density (Fig. 4b), which ranges from zero to 13,090 persons per square kilometer was divided into eight classes of suitability using equal intervals ranging technique. Eight classes were adopted since the population density map showed a higher variability as proximity to the road.

The suitability of the climate for irrigation was estimated by calculating the monthly rainfall deficit (rainfall minus potential evapotranspiration) for both baseline and future time horizons (Worqlul et al., 2015). A positive deficit reflects no irrigation requirement, while a negative value suggests a need for irrigation. The monthly rainfall deficit was aggregated to annual amounts. The rainfall deficit was reclassified into eight classes of suitability using an equal interval ranging technique.

The weight of the factors estimated with a pair-wise comparison was distributed to the different suitability classes with an equal interval ranging technique. Thereafter, Weighted Overlay Analysis was used to assess the preliminary suitability of land for irrigation. The preliminary suitability map was then constrained by land use types that limit the suitability of the land for surface irrigation such as water bodies, wetlands, urban, forest, and protected areas to create the final land suitability map.

2.2.6. Climate change effect on land use suitability

The likely effect of climate change on land use suitability is a major concern globally in recent years (Olesen and Bindi, 2002). Climate change is expected to affect the suitability of land for agriculture at a different level depending on the direction and magnitude of change. It will have a significant impact in sub-Saharan African countries and specifically Ghana where the majority of the food production is relying

Table 3
Pair-wise comparison matrix and weights of factors.

Factors	Soil	Land use	Population density	Road proximity	Rain deficit	Slope	Weight (%)
Soil	1	3	1/3	2	1/2	1/3	11.4
Land use	1/3	1	1/4	2	1/4	1/4	6.4
Population density	3	4	1	3	2	1/2	24.9
Road proximity	1/2	1/2	1/3	1	1/5	1/3	5.8
Rainfall deficit	2	4	1/2	5	1	1/2	20.1
Slope	3	4	2	3	2	1	31.4
Total							100

on a rainfed system (Cooper et al., 2008). In this study, the effect of climate change on the suitability of land due to climate change were evaluated by substituting the rainfall deficit of baseline period by the respective future time horizons climate data while keeping the other factors of the MCE similar (Fig. 2). Then the change in land use suitability due to climate change in the future time horizons were compared with the baseline period of estimated potential land suitability.

3. Results and discussion

3.1. Weighting of factors for surface irrigation suitability mapping

The pair-wise comparison matrix and overall weights of the factors selected for the study are shown in Table 3. The slope was the most important factor for suitability of land for surface irrigation in Ghana indicating that land preparation may require a significant initial investment that weakens the economic feasibility. The population density was the second most important factor for determining the suitability of an area for irrigation, highlighting the strong role of market access for agricultural input and produce. Rainfall deficit and soil showed modest influence on land suitability, while land use and road proximity showed the lowest influences. The credibility of the pair-wise comparison was tested with a consistency ratio to test if the matrix ratings were randomly generated. The result indicated that the comparison matrix to be trustworthy, with a consistency ratio of 5% (Ceballos-Silva and Lopez-Blanco, 2003; Saaty, 1980).

3.2. Preliminary land suitability analysis for surface irrigation

The factors outlined above were reclassified into different levels of suitability. Fig. 6 illustrates the reclassified factors affecting land suitability for surface irrigation in Ghana. The overall weights of the factors were distributed to the different levels of suitability classes by an equal interval ranging technique. For example, the overall weight for land use, which was 6.4 (Table 3) was distributed to the four classes of suitability, pixels which are classified as highly suitable (agricultural land) received a value of 4/4 * (6.4), the second most suitable land use group (grassland) received 3/4 * (6.4) and the third suitable group (shrubland) received a weight of 2/4 * (6.4), and the least suitable group received 1/4 * (6.4) weights. The most important factor, slope, indicated that the majority of the country (74%) was classified as highly and moderately suitable for agriculture. The reclassified rainfall deficit indicated a near-normal distribution; where the moderate and marginally suitable land totals 71% while the rest tends towards extremely dry and extremely wet.

After the overall weights of the factors were distributed to the different levels of suitability groups, the preliminary suitability map was computed by overlaying weighted factors using a Weighted Overlay Tool available in ArcGIS under Spatial Analyst toolbox. The preliminary land suitability map provided values which ranges between 26% and 94%, where 26% represents the lowest suitability and 94% the most suitable land (Fig. 7). A constraint map was used to exclude areas that are not suitable for irrigation. The most suitable land was extracted with a variable threshold from 80% to 94% (with a 1% increment) from the preliminary suitability map, and the area above the threshold is shown in Fig. 8. For example, at a threshold of 85%, there were thousands of suitable areas ranging from 1 km^2 to 35 km^2. At the 85% threshold, nearly 2% of the landmass was suitable for surface irrigation, and at the 80% threshold, nearly 9% (22,600 km^2) of the land was suitable for surface irrigation.

The potential suitable lands with a suitability of 80% and above were extracted for the three major river basin systems in Ghana (Table 4). This type of analysis can help in identifying and prioritizing land use planning at basin level. The Volta River basin, which covers approximately 67% of the country has the lowest potential suitable land for irrigation. The South Western River Basin System, which is the second largest basin covering 24% of the country has the largest suitable land for irrigation (9690 km^2). The Coastal River System is the smallest basin but has the highest percentage (37%) of suitable land for irrigation.

3.3. Potential of shallow groundwater

The estimated depth to groundwater in Ghana is 14 m on average from the surface, with a maximum depth of 50 m. The majority of the country (98%) has groundwater access under 25 m from the ground surface. The aquifer productivity indicates that the borehole potential yield in the country ranges between 0.1 and 20 l/s. A large proportion of the country (56%) has aquifer potential yield between 1 and 5 l/s, while 2% of the country has the highest aquifer potential yield between 5 and 20 l/s.

The most suitable land suitable for agriculture, which has a suitability value of greater than 80% was superimposed over the borehole potential yield and depth to groundwater map to evaluate the potential of shallow groundwater for irrigation and its accessibility using simple water-lifting technologies. The potentially suitable land has shallow groundwater access ranging between 1 and 50 m from the surface, with an average depth of 12 m (Fig. 9a). The borehole yield over the potential suitable land ranges between 0.0 and 13.55 l/s and the average borehole yield was approximately 2.5 l/s (Fig. 9b). The combination of access to shallow groundwater and moderate borehole yield (approximately a recharge of 600 mm) makes the suitable land favorable for irrigation development using human, animal, diesel and solar powered water lifting technologies.

3.4. Climate change and its effect on land use suitability for irrigation

3.4.1. Rainfall for baseline and future time horizons

The downscaled rainfall data of the future time horizons were compared with the baseline period. Fig. 10a and b shows the rainfall difference between baseline and future time horizons. The projected rainfall data difference the baseline period (Fig. 10a and b) did not show a consistent change throughout the country for both future time horizons. In 2050s, approximately 65% of the country will receive a higher rainfall while a reduction in rainfall is expected in 32% of the country located in the southern coast compared to the baseline period. In 2070s, the area receiving higher rainfall will increase to 68% of the country compared to the baseline period. In general, under RCP 4.5

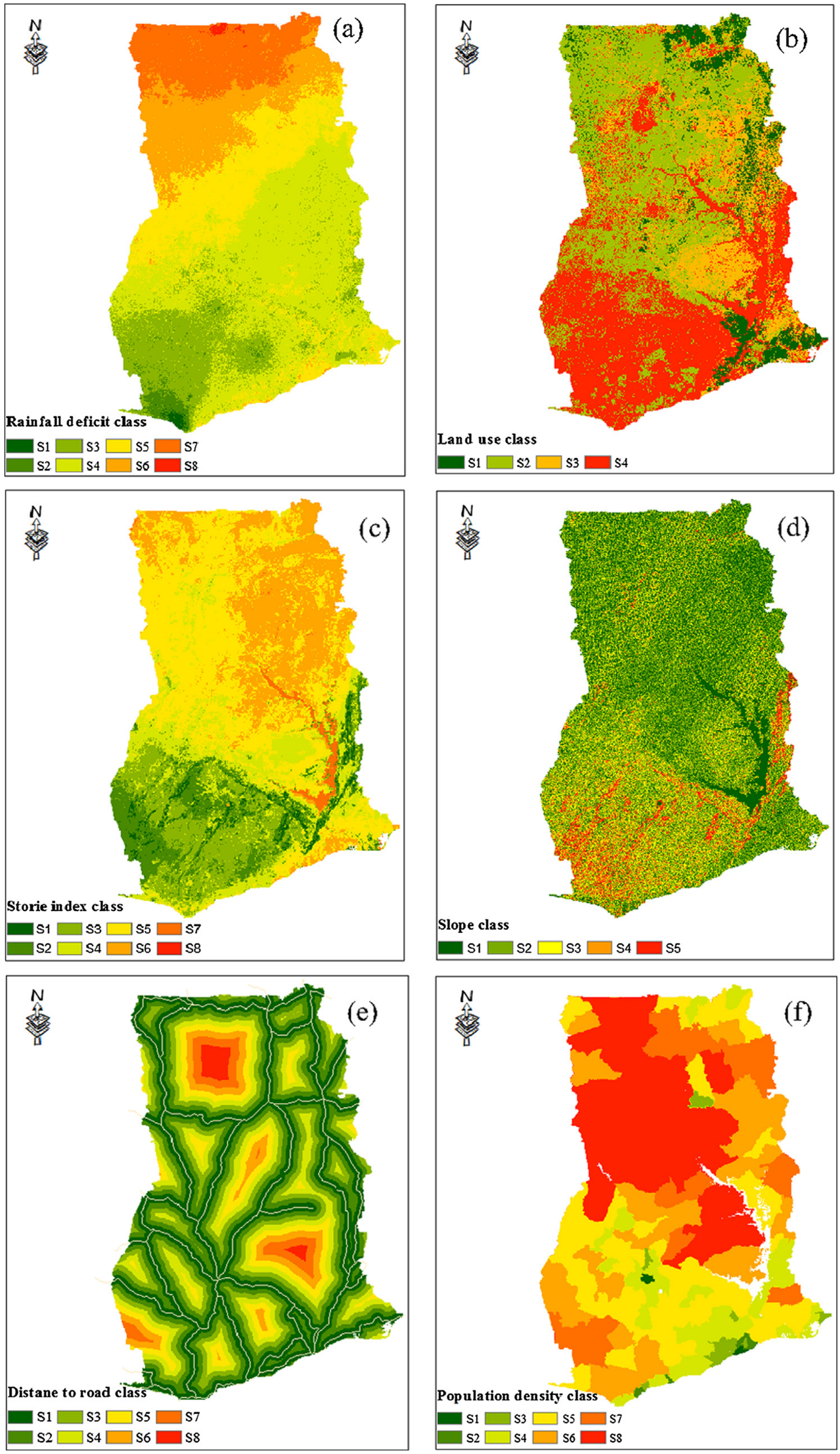

Fig. 6. Reclassified factor maps: (a) rainfall deficit, (b) land use class, (c) Storie Index class, (d) slope class, (e) distance to the road class and (f) population density class. S1 represents highly suitable areas and as the number increases, the suitability level decreases.

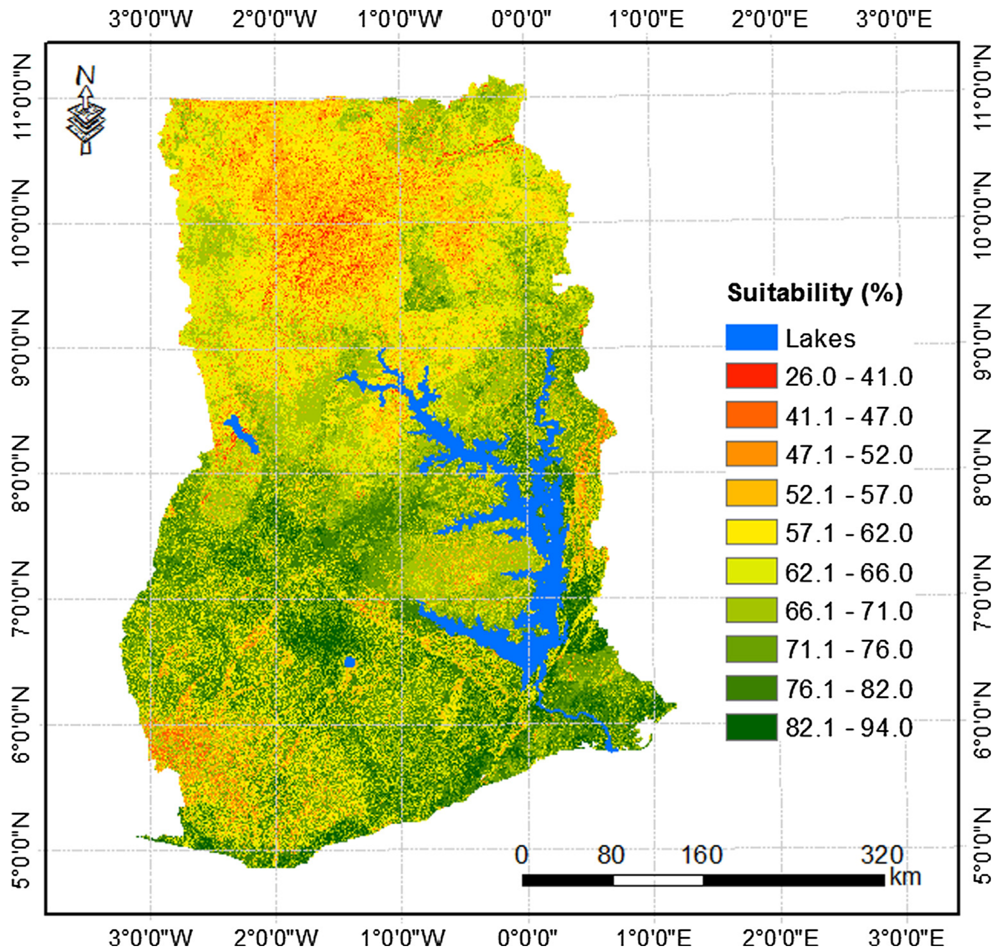

Fig. 7. A preliminary suitable land for irrigation map; 94% shows the most suitable area for irrigation while 26% shows the least suitable land.

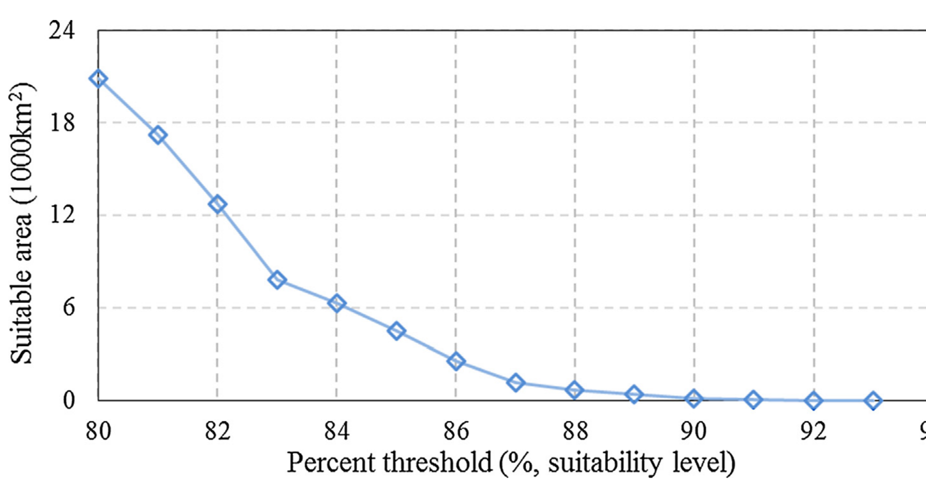

Fig. 8. Suitable irrigation area (in 1000 km^2) at different suitability levels. For example, approximately 4500 km^2 of the land is suitable at a suitability threshold of 85% and 12,700 km^2 land is suitable at a suitability threshold of 82%.

scenario, rainfall will increase in the northern part of the country (drier part of the country) under both future time horizons, while a reduction will be expected in the southern part of the country (wettest region) (Fig. 10a and b). Overall, on average, the country will receive an additional 15 mm rainfall more from the baseline period in 2050s and it will increase to 20 mm in 2070s. This indicates that under future time horizons, the small change in rainfall could not be the major limiting factor for land suitability analysis compared to the baseline period. A similar conclusion was also drawn by Srivastava et al. (2018) conducted in the central part of Ghana.

3.4.2. Temperature and potential evapotranspiration in the future time horizons

The projected future time horizon minimum and maximum temperature were averaged and the difference from the baseline period was computed (Fig. 11a and b). The rate of change of temperature is higher in 2070s compared to 2050s. In 2050s, the average temperature will increase by 2.0 °C from the baseline period. In this period, the average

Table 4
Potential suitable land area in the major river basins of Ghana.

River basin	Basin area (km^2)	Potential irrigable land (km^2)	Percent potential (%)
Coastal River System	20,446	7568	37.0
South Western River System	58,189	9687	16.6
Volta Basin System	159,793	5337	3.3
Total	238,428	22,592	9.5

temperature will increase by 1.5 to 2.2 °C in the majority of the country (66%). In 2070s, the average temperature will further increase by 2.6 °C from the baseline period. In the majority of the land (88%) temperature will increase by 2.3 to 3.1 °C. The rising temperature expected in the future will significantly impact plant development and productivity. Rising temperatures will increase the potential evapotranspiration on average by 6.0% and 7.6% in the 2050s and 2070s, respectively. The projected temperature and evapotranspiration together with population growth will place a substantial demand on water leading to inter-sectoral competition over the limited resources.

3.4.3. Climate change impact on the land use suitability

The rainfall deficit of the projected time horizons was compared with the baseline period. The result indicated that the rainfall deficit in 2050s will increase by 14% from the baseline period and in 2070s it will further increase by 20% from the baseline period. The difference in rainfall deficit between future and baseline period indicated that in 2050s, rainfall deficit will increase in 92% of the country and in 2070s, the rainfall deficit will further increase in 98% of the country (Fig. 12a and b).

The rainfall deficit of the future time horizons was used as input to MCE to identify the potential land suitable for irrigation in the future time horizons and the difference in land suitability from the baseline period was computed. The projected land suitability analysis indicated that in the 2050s, 9.5% of the baseline period suitable for irrigation will be unfavorable for irrigation due to increasing rainfall deficit and in 2070s the unfavorable land area will further increase to 17%. The difference between future and baseline land suitability analysis is shown in Fig. 13a and b. Generally, in the 2050s, 53% of the land and in 2070s 47% of the country will not be affected by climate change when compared with the baseline suitability. However, in both future time horizons, the central part of Ghana will be highly affected by climate change.

Although rainfall gains are expected in the majority of the country in the future time horizon, overall the net gain due to climate change in Ghana will be negative due to a rising temperature. Therefore, the government of Ghana should plan adoption measures to reduce the plausible impact of rising temperature, higher evaporation, and greater rainfall variability. The planning should include enhancing the sustainable use of water resources, crop diversification and planting a new variety of temperature tolerant crops. The government should also be prepared to control pests and diseases which may expand their geographic territory as the climate warms.

The most suitable land for the projected time horizons was extracted with a variable threshold from 80% to 94% (with a 1% increment) and the percentage area difference from the baseline period was calculated for each group (Fig. 14). The result indicated that in 2050s, the land use suitability decreased by more than 5% in the 60% of the land suitability groups (Fig. 14). In 2017, the land use suitability decreased across all of the suitability groups by more than 10%.

The potential suitable lands of the 2050s and 2070s with a

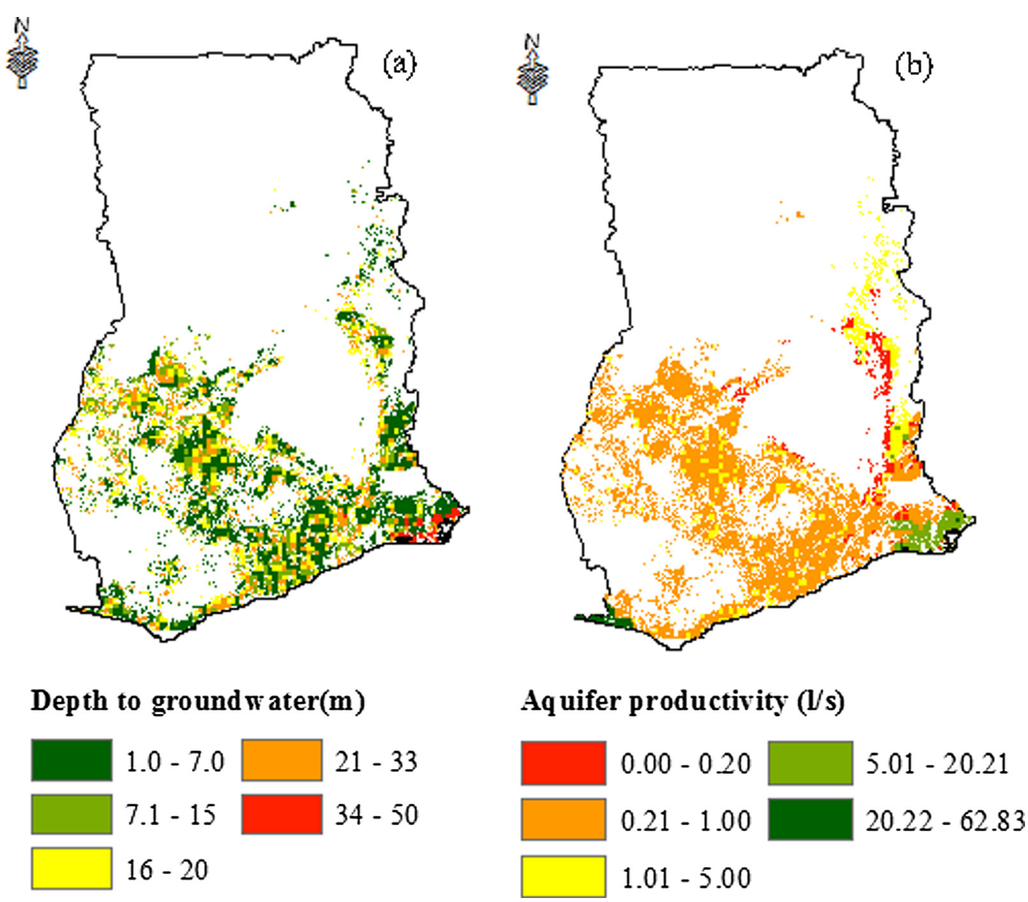

Fig. 9. (a) Depth to groundwater (m) and (b) Aquifer productivity (l/s) over the potential suitable land (suitability greater than 80%).

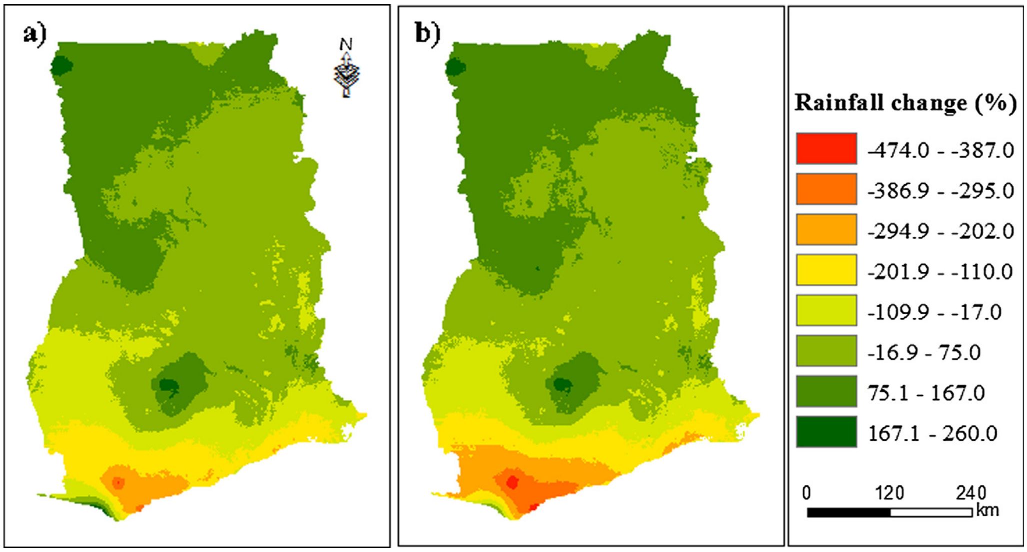

Fig. 10. Annual average rainfall change from the baseline period in the future time horizons (a) Rainfall change from the baseline period in 2050s (2041 to 2060) and (b) Rainfall change from the baseline period in 2070s (2061 to 2080).

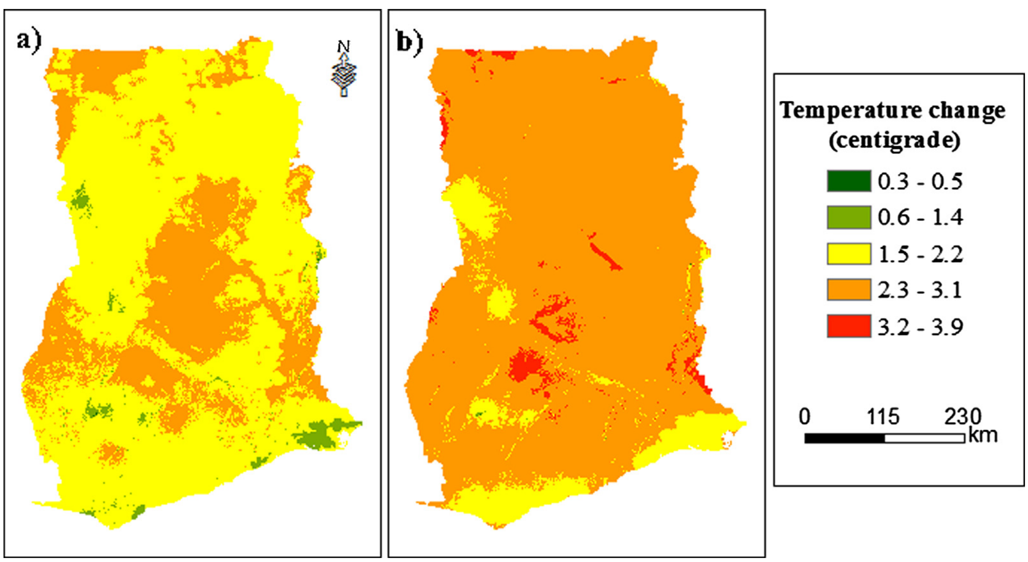

Fig. 11. Annual average temperature difference of the future time horizons from the baseline period (a) Average temperature change from the baseline period in 2050s (2041 to 2060) and (b) Average temperature change from the baseline period in 2070s (2061 to 2080).

suitability of 80% and above were extracted for the three major river basin systems of Ghana (Table 5). The result indicated that for both future time horizons the suitable land in South Western River Basin System will increase by 12% and 2% for 2050s and 2070s, respectively, while a significant suitable land area reduction will be expected in Volta and Coastal River Systems for both future time horizons (compare with Table 4).

3.4.4. Irrigation potential of the groundwater during the future time horizons

The irrigation potential of the groundwater during the future time horizons was not evaluated due to the absence of projected groundwater data and due to the complexity of the groundwater response in the future. However, in general, climate change will have a significant effect across the different water balance components (precipitation, evapotranspiration, soil moisture storage, groundwater and surface runoff) due to a rising temperature and rainfall variability (Abdo et al., 2009; Adem et al., 2014; Eckhardt and Ulbrich, 2003; Worqlul et al., 2018b).

In Ghana, the majority the potential suitable land for irrigation is located in the in the southern part of the country (Fig. 9), which is expected to experience a significant rainfall deficit in the future time horizons (Fig. 12). The rising temperature, which increases evaporation and transpiration by plants will likely reduce recharge to the groundwater system. This highlights the extent of climate change impact on Ghana where most of the population is located (Fig. 4b) with a greater demand.

4. Conclusions

This study is the first of its kind to provide a spatially explicit land suitability analysis for the baseline and future time horizons in Ghana. The findings indicate that there is a significant area of land suitable for irrigation that could be developed with shallow groundwater under the baseline condition. A large portion of the suitable land is located in the South Western River Basin System with shallow groundwater access (< 25 m) that has a moderate borehole yield (2.0–4.6 l/s), which made the basin highly favorable for small-scale irrigation using simple water

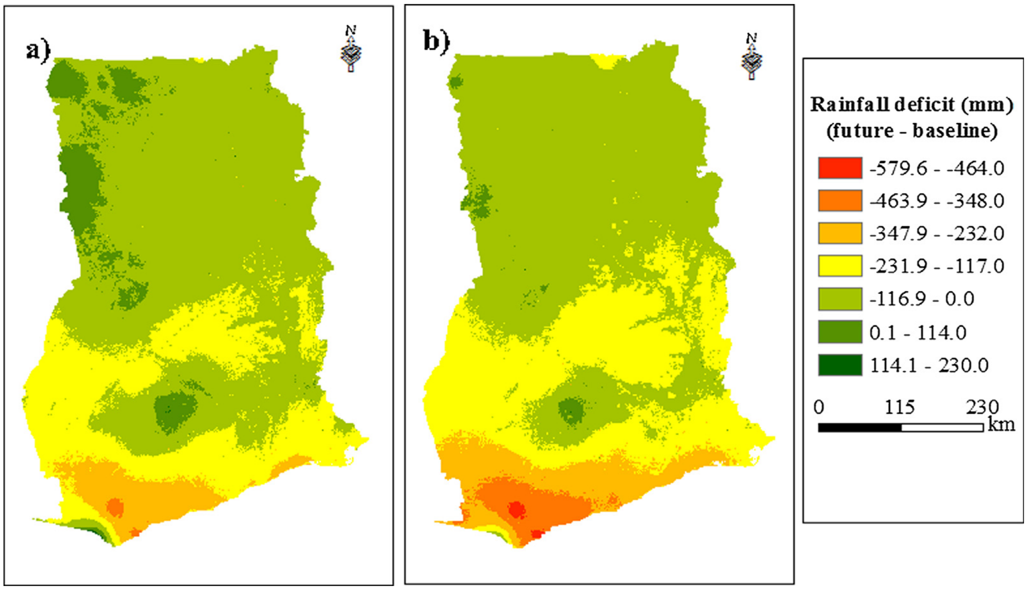

Fig. 12. Rainfall deficit between future time horizons and baseline period (a) 2050s and (b) 2070s. The negative values indicate a further rainfall deficit increase in the future time horizon and positive values indicated a reduction in rainfall deficit.

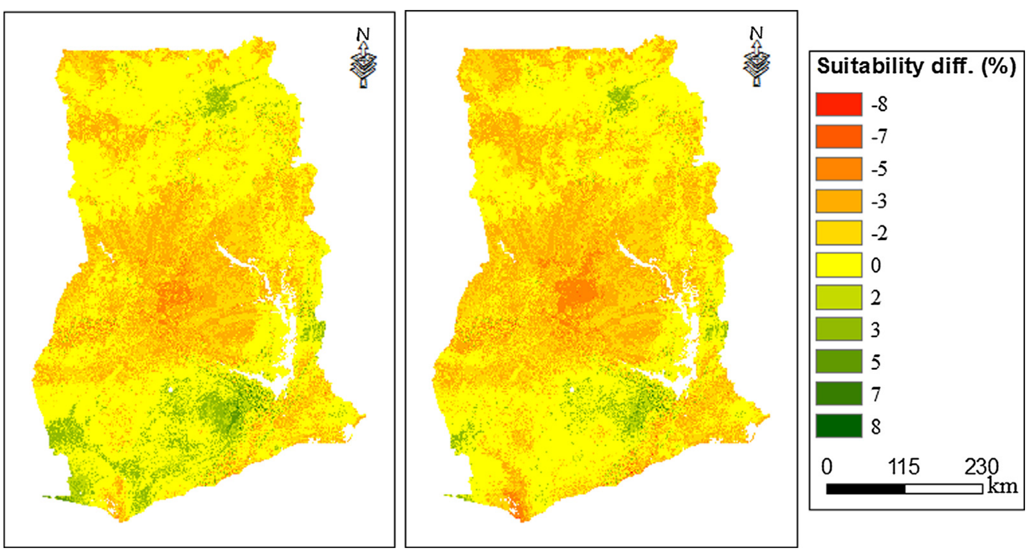

Fig. 13. Relative change of land suitability between future time horizons and baseline period (a) 2050s and (b) 2070s. The negative values indicates a reduction in suitability from the base period, a positive value indicates an increase in suitability while zero indicates no change in suitability.

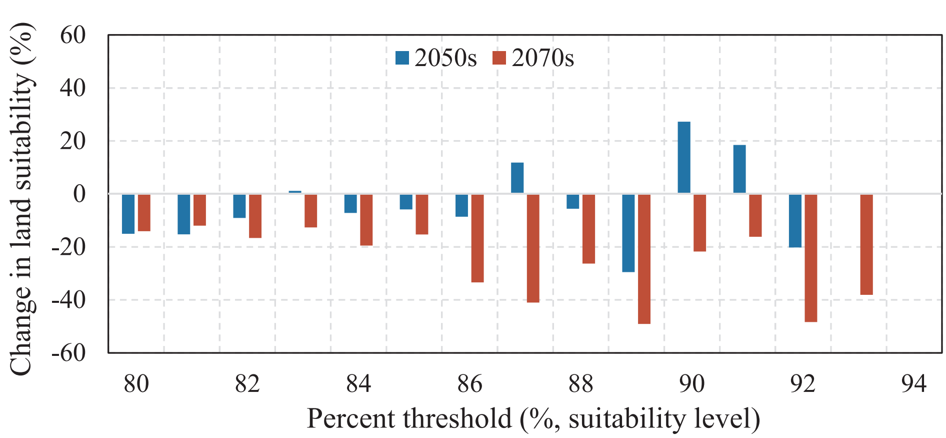

Fig. 14. Percentage change of suitable land during the future time horizon were compared to the baseline period. The negative values indicate a reduction in suitability from the baseline period and a positive value indicates an increase in land suitability for irrigation.

Table 5
Potential suitable land for irrigation under the future time horizons in the major river basins of Ghana.

River basin	Basin area (km^2)	Potential irrigable land in 2050 s (km^2)	Potential irrigable land in 2070 s (km^2)
Coastal River System	20,446	6433	5892
South Western River System	58,189	10,835	9802
Volta Basin System	159,793	3178	3058
Total	238,428	20,446	18,751

lifting technologies making the area favorable for small-scale irrigation using human, animal, diesels and solar powered water lifting technologies.

The climate change study under the HadGEM2-ES RCP 4.5 emission scenario shows the northern part of Ghana will benefit from increasing rainfall for both future time horizons. Overall, in Ghana, on average rainfall will increase in both future time horizons by 15 mm and 20 mm from the baseline period in 2050s and 2070s, respectively. However, the average temperature will rise by 2.0 °C and 2.6 °C in 2050s and 2070, respectively and the rise in temperature will increase the potential evapotranspiration by 6.0% and 7.6% in the 2050s and 2070s, respectively. Due to climate change, 9.5% and 17% of the potential land suitable under the baseline period will be unfavorable in 2050s and 2070s, respectively. This suggests that climate change adaptation and mitigation policies should be in place to maintain the suitable land for irrigation. For example, there are several land and water management interventions (e.g. mulch, conservation agriculture, etc) that shifts the non-productive evapotranspiration to productive evapotranspiration, and thereby maintain or even improve land and water productivity in the face of climate change.

This study was intended to provide valuable information to policy-level decision-makers on the potential to invest in irrigation using groundwater in Ghana. The maps and identification of suitable areas can inform program planners and investors regarding the optimal locations for intensification of agriculture using groundwater irrigation. Ghana's agricultural policy, as well as the more specific irrigation policy, foresees the need to expand irrigated agriculture in order to achieve food security aims and expand the contribution of agriculture to economic growth. Studies that apply methods such as MCE can be relevant tools for targeting investments to achieve impact.

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Appendix. -1: Temperature effect on potential evapotranspiration

Evapotranspiration is the second largest water budget of the water balance components (Vörösmarty et al., 1998; Wilson et al., 2001). Temperature-based evaporation methods are common which includes Penman–Monteith (Penman, 1948), Hargreaves (Hargreaves and Samani, 1985), Thornthwaite (Thornthwaite, 1948), Blaney-Criddle (Brouwer and Heibloem, 1986) among others. Penman–Monteith method is one of the standard methods for estimating potential evaporation (ETo). To understand the effect of a change in temperature on potential evapotranspiration, Penman-Monteith was used to estimate the potential evapotranspiration by changing the temperature with synthetic scenarios of changing temperature between −5°C to 5 °C. The hypothetical temperature change indicated a strong linear association with the potential evapotranspiration (Fig. A1). For a one-celsius temperature increase, the potential evapotranspiration will increase by 2.9%; potential evapotranspiration increases linearly with increasing temperature (Fig. A1). A five Celsius increase from the baseline will increase the potential evapotranspiration by 14.6%.

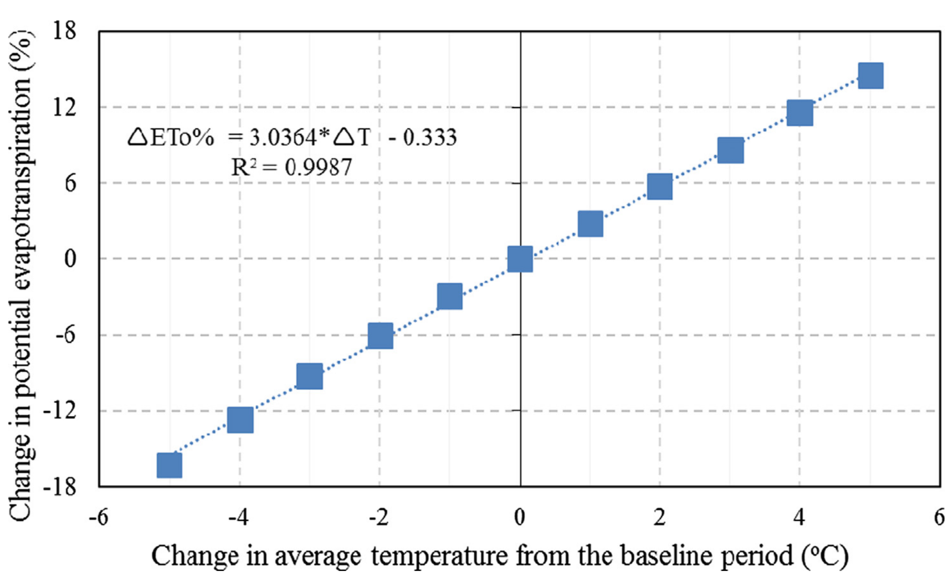

Fig. A1. Effect of change in temperature on potential evapotranspiration for a synthetic temperature change scenario from the baseline period.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.compag.2018.12.040.

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