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The use of the multi-criteria analysis for the exploration of surface irrigation potential zones: A case of the Didesa sub-basin, Abay basin, Ethiopia

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Abstract: This paper presents a study conducted using the Multi-Criteria Analysis (MCA) to explore surface irrigation potential zones in the Didesa sub-basin of the Abay basin in Ethiopia. Physical land features, such as land use / land cover (LULC), slope, soil depth, drainage, and road proximity, along with climate factors like rainfall and evapotranspiration, and population density, were identified as criteria for the exploration. The analytic hierarchy process (AHP) is a powerful structured decision-making technique commonly used for complex multi-criteria analysis problems where multiple criteria need to be considered. The importance of the criteria was prioritised and ranked in the analytic hierarchy process (AHP). Five qualitative-quantitative based surface irrigation potential zones were identified, namely highly suitable (48.40%), moderately suitable (27.26%), marginally suitable (13.27%), not suitable (4.91%), and irrigation constraints (6.16%). The consistency of the AHP technique in the exploration of surface irrigation potential zones is evaluated by the consistency index at *CI* = 0.011 and confirmed the correctness of weights assigned for the individual key factor in the AHP. The accuracy of the potential zones generated in the AHP was evaluated with ground-truth points and a supervised LULC classification map. Moreover, a good agreement was made among the classes with the kappa index (*KI* = 0.93). Therefore, the application of the MCA for the exploration of surface irrigation potential zones was successful, and the results of the study will be useful to strengthen the irrigation in the explored potential zones.

Keywords: analytic hierarchy process (AHP), key factors, multi-criteria analysis (MCA), physical land features, potential zones

INTRODUCTION

Globally, more than 40% of the Earth's land is used for agricultural practices. This trend is consistent with many African countries (Worqlul *et al.*, 2018; Girma, Gebre and Tadesse, 2020). As studies conducted in Ethiopian agricultural sectors reveal, about 80% of the labour is getting involved in agriculture (Bagherzadeh and Daneshvar, 2011), which is mainly focused on the rain-fed agricultural system. The agriculture practices in Ethiopia are dependent on rain-fed, which is vulnerable to the variability of rainfall and other physical land features (Iticha and Takele, 2018; Mandal, Dolui and Satpathy, 2018). More than 95% of the food source in Ethiopia derives from the low-yielding agricultural system (rain-fed) and rainfall is the unique and single factor in agriculture (Olika and Iticha, 2019).

A significant problem associated with the dependency on rain-fed agriculture is that there was no study conducted that helps the community to implement irrigation-based agricultural systems (Scanlon *et al.*, 2005; Panagos *et al.*, 2018; Dawit *et al.*, 2020). The dual agriculture system is the best way of enhancing and increasing productivity (Dawit *et al.*, 2020), and that is why the exploration of surface irrigation potential zones in this study is very important. Less skilled and poor farmers can profit from of surface irrigation, and it alleviates poverty, strengthens food security (Pimentel and Burgess, 2013), and improves the quality of life for low-income farmers. Although the local farmers have little knowledge of surface irrigation, more than 95% of the world uses it (Dinka, 2020). Despite the high significant surface water potential in the sub-basin (Raviraj, Kuruppath and Kannan, 2017; Gebrie *et al.*, 2018; Hamdani and Baali, 2020), there is no single piece of land that the farmers are utilising for irrigation. Very limited quantitative study is available on the exploration of surface irrigation potential zones (Balsubramanian, 2017; Raviraj, Kuruppath and Kannan, 2017; Gebrie *et al.*, 2018) in the country, and this study can put a milestone for the further analysis.

The multi-criteria analysis (MCA) method involving the analytic hierarchy process (AHP) is extensively used for different purposes like the land suitability analysis (Lange Salvia *et al.*, 2019), urban public transport (Nosal and Solecka, 2014), and the evaluation of a manufacturing process based upon continuous five axes CNC (Computerized Numerical Control) machine-tools (Bologa *et al.*, 2016). In this sense, this study explores potential zones for surface irrigation using the MCA approach called the AHP in ArcGIS version 10.4. Internationally, studies (Worqlul *et al.* 2017; Ahmad *et al.*, 2020; Dibaba, Demissie and Miegel, 2020) are available on the application of the AHP in assessing land suitability for surface irrigation purposes. However, no study was done in this sub-basin. In the AHP, key significant factors, such as physical land features and climate data, are integrated and indexed to generate surface irrigation potential zones (Dibaba, Demissie and Miegel, 2020). To explore the surface irrigation potential zones (Al-Adamat, 2012) in the sub-basin, the availability of surface water resources from the river networks on the basis of physical land features was evaluated first.

MATERIALS AND METHODS

DESCRIPTION OF THE STUDY AREA

The Abay River lies in the west of Ethiopia between latitude 7° 45', and 12°46'N, and longitude 34°06' and 40°00'E. Didesa is one of the sub-basins found in the basin which covers a total area of 19,630 km^2 and extends over a few political-administrative zones, such as East and West Wollega, Ilubabor, Jimma, and Kamashi (Paola de, 2014; Dessalegn *et al.*, 2017). The sub-basin is situated (Fig. 1) between 8°00'N and 10°00' and 35°00'38°00' latitude and longitude, respectively. The topographic condition of the study area is characterised by a long valley, created by erosive actions of the sub-basin river flowing from the highland to the lowland of the sub-basin with an average elevation ranging from 630 to 1500 m a.m.s.l. (Abay *et al.*, 2017). The mean annual rainfall varies between 45 mm to 3352 mm (Prasannakumar *et al.*, 2012). The sub-basin has the highest contribution of any other tributaries of the Abay River. The Didesa River receives water from different tributaries, such as the Dabena River, Wama, Idris and Shifa. The Didesa River has been gauged since 1960 at the station known as "Didesa near Arjo" and the mean annual flow at this station is 117 m^3·s^{-1}. This includes all the upstream areas drained by the Urgessa and Temsa rivers with a mean average flow of 1.07 and 1.29 m^3·s^{-1} (Abay *et al.*, 2017).

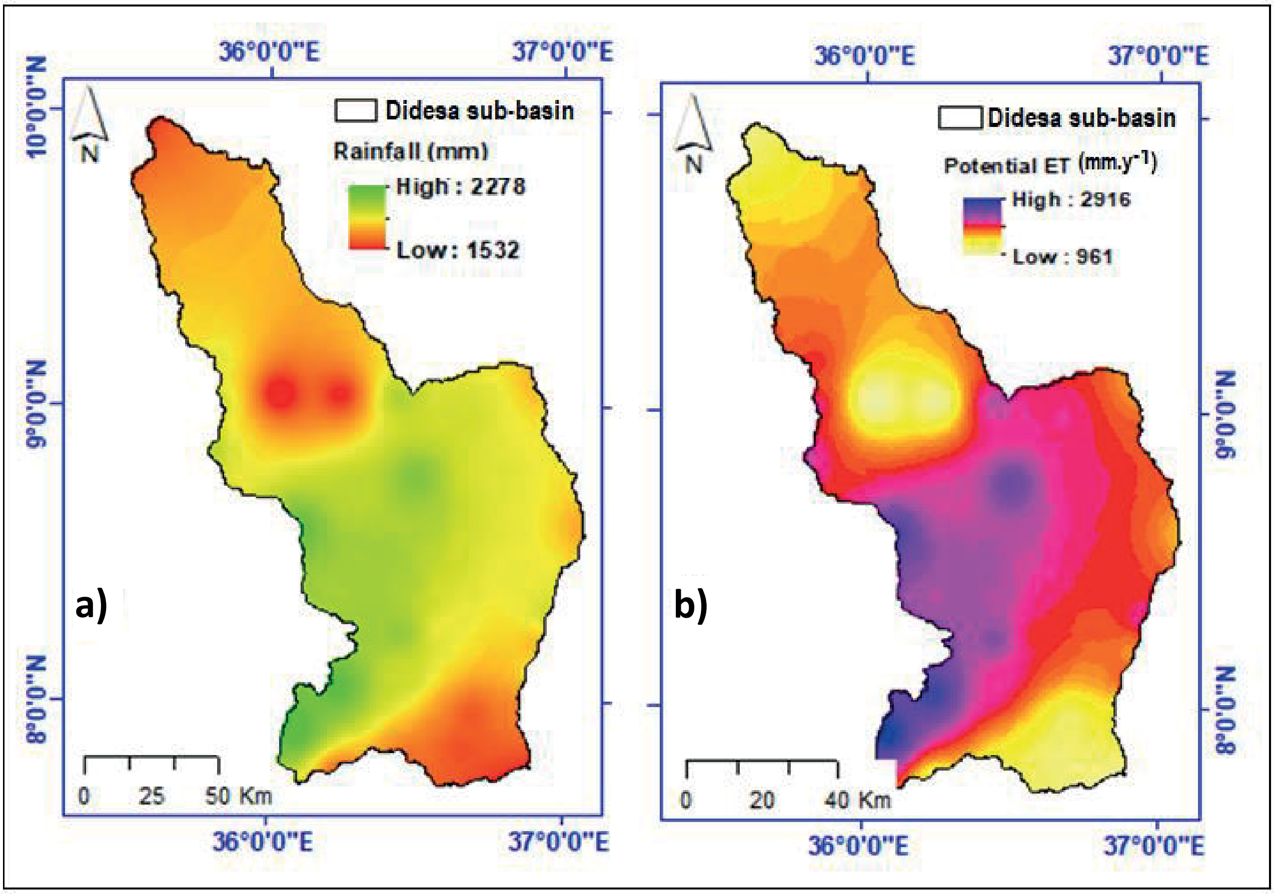

Fig. 1. Map of the rainfall and potential evapotranspiration (*ET*) spatial distribution in the Didesa sub-basin generated in inverse distance weighted (IDW): a) rainfall, b) potential evapotranspiration; source: own elaboration

SELECTION OF THE KEY FACTORS

Beside the rain-fed agriculture practice, irrigation has a paramount role for food security and improvement of living conditions in the sub-watershed (Yan *et al.*, 2018; Maqsoom *et al.*, 2020). The topographical conditions, physical terrain features, and climate are considered as a primary criterion while selecting significant factors for the exploration of surface irrigation potential zones (Hammouri, El-Naqa and Barakat, 2012).

Field observations and reconnaissance survey were made with different experts from the Agriculture Office, Irrigation Authority Office, and other volunteered environmentalists to determine key significant factors for the analysis of suitable potential zones. Because of the topographic and availability of surface water sources, the Didesa sub-basin was confirmed for the exploration of surface irrigation potential zones. To explore the surface irrigation potential zones in this sub-basin, the key significant components, such as terrain, slope, soil, and rainfall, were tested as surface irrigation development criteria (Mandal, Dolui and Satpathy, 2018; Andualem *et al.*, 2019; Tolche, 2020). Data obtained from the local government office in a vector and raster format had different pixel resolution and the resampling technique in ArcGIS 10.4 version was applied and brought to the same resolution (30 × 30 m). The key significant elements were analysed and reclassified using a pair-wise comparison matrix in ArcGIS 10.4 version (Hamdani, 2004; Dar, Rai and Bhat, 2020; Hategekimana *et al.*, 2020). Surface irrigation potential zones were developed after the reclassification and weighted components were integrated with the overlay analysis with the spatial tool analyst in ArcGIS environment (Desta and Lemma, 2017; Worqlul *et al.*, 2017; Dibaba, Demissie and Miegel, 2020).

The combination of physical land features (slope, soil, and land use), climate factors (rainfall) are an indicator of surface irrigation potential zones. For this specific study, rainfall, slope, soil and land use were considered as an indicator for the exploration of surface irrigation potential zones. Historical mean annual rainfall of 15-years (2005–2019) and the corresponding evapotranspiration (*ET*) in the sub-basin were used for the exploration of surface irrigation potential zones. The areal distribution of these factors is presented in Figure 1a and 1b.

The land use used in this study was extracted from Landsat 8 image (Al-Nahmi *et al.*, 2016; Akinluyi, Olorunfemi and Bayowa, 2018; Kayet *et al.*, 2018). The slope of the study area was generated from the Digital Elevation Model (DEM) of 12.5 × 12.5 m spatial resolution downloaded from CEOS (no data) and NASA (no data) with the terrain corrected high resolution DEM (Chandra Bose, Giridhar and Viswanadh, 2010; Saitaptim, 2011). The data and temporal resolution for each data are summarised in Table 1.

The physical land features (land use/land cover, slope, distances, availability of surface water sources, and soil), climate attributes (rainfall and potential evapotranspiration (*ET*)) and socio-economic factor (population density) are considered as primary criteria for the selection of factors that are significant for the exploration of surface irrigation potential zones (Hammouri, El-Naqa and Barakat, 2012). Field observations and reconnaissance survey were made with different experts from the Agriculture Office, Irrigation Authority Office, and other volunteers to choose the key significant factors used in the multi-criterion analysis (MCA). Based on physical evidences, availability of surface water sources, and availability of data in the Didesa sub-basin, the key significant factors, such as land use/land cover (LULC), soil, slope, population density, distance and rainfall were confirmed as the parameters for the MCA during the exploration of surface potential zones.

ANALYTIC HIERARCHY PROCESS (AHP)

The analytic hierarchy process (AHP) is a very popular multi-criteria decision method and has been applied in a wide variety of areas including suitable land selection, groundwater exploration, and water resources allocation and planning. Since the exploration of potential zones needs a combination of physical land features, climate, and socioeconomic factor (USBR TSC, 2005; Worqlul *et al.*, 2017; Ahmad *et al.*, 2020), it is a best alternative to use the AHP. The degree of importance for each significant factor is different and for this purpose, the analytic hierarchy process (AHP) was implemented to identify relative significance of each key factor (Gedam Berhanu and Dagalo Hatiye, 2020; Hamdani and Baali, 2020). A pair-wise comparison matrix developed in the AHP helps to rate the relative importance of a factor corresponding to the other factors, with a rating scale of 1 to 9 – Table 2 (Andualem *et al.*, 2020).

Table 1. Summarised data with the sources and spatial/temporal resolution

S. No	Data	Sources of the data	Spatial/temporal resolution
1	land use	http://geoportal.rcmrd.org	available for the year 2018
2	road networks	Ministry of Water Resources	Didesa sub-basin
3	soil	Ministry of Water Resources	available for the year 2018
4	river networks	Ministry of Water Resources	Didesa sub-basin
5	DEM(m)	NASA (no data)	Didesa sub-basin
6	rainfall (mm)	Ministry of Water Resources	15-years
7	groundwater depth (m)	Ministry of Water Resources	Didesa sub-basin

Source: own elaboration.

Table 2. Analytical hierarchy process scale and judgment

Scale	Judgment
1	equal importance
3	moderate importance one over the over
5	essential or strong importance
7	very strong or demonstrated importance
9	extreme or absolute importance
2, 4, 6, 8	intermediate values between the two adjacent judgments

Source: own elaboration.

STEPS IN THE ANALYTIC HIERARCHY PROCESS (AHP)

In the AHP, it is clear that there are several criteria that can be evaluated in several ways. First of all, the AHP technique predicts issues to be solved in three stages. The first stage is to identify the issue, the next stage proposes different alternatives or possible solutions, and lastly, the third stage evaluates possible solutions against specific criteria. In general, there are four steps in the AHP during decision making regarding the exploration of surface irrigation potential zones, as shown in Figure 2. The natural environment of a given watershed is governed by its physical characteristics, such as LULC, soil, and slope. The land that is to be used for irrigation is subject to these physical features. Without knowing the physical evidences of a catchment, it is meaningless to make a decision about the selection of surface irrigation potential zones. The importance of these physical features for the exploration of suitable surface irrigation potential zones are presented in the following sections.

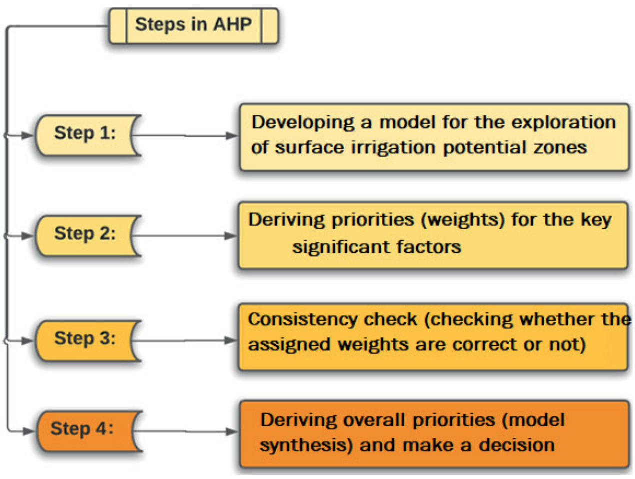

Fig. 2. The detailed steps in the analytic hierarchy process (AHP) during making a decision; source: own elaboration

LAND USE

The purpose for which the land serves is called land use (Fayas, 2019). The types of land use and the degree of suitability for surface irrigation are correlated. The land use classification is a commonly used technique to get information about the land cover (Thapa, 2020; Yulianto *et al.*, 2020). Land use and land cover are interconnected and describe physical land types. Such information from the exploration of surface irrigation potential zones (Fig. 3a, b) is very important in decision making. Generally, there are eight LULC classes (tress cover areas, shrubs cover areas, grassland, cropland, vegetation covers, bare lands, built-up areas and open water) in the sub-basin and these are divided into four classes (as cropland, grassland, shrubs cover areas and vegetation covers) based on the suitability of the land for cultivation.

SOIL DEPTH AND TEXTURE

The exploration of surface irrigation potential zones depends on soil properties such as depth and texture. Soil depth is one of the most important properties of soil and the major factor for identifying appropriate soil characteristics that is suitable for crops to receive water and essential minerals. Soil is one of the physical land features, and its suitability is evaluated in terms of physical and chemical properties (Gebremariam, 2010; Das and Pardeshi, 2018). The physical component of soil in this study includes the land suitability evaluation which relies on properties such as infiltration capacity, sensitivity to runoff, and nutrient composition. The other soil properties, such as texture, chemical composition, soil depth, and drainage class, were extracted from data provided by the Ethiopian Ministry of Water Resources. Since plant roots grow and propagate in the soil, soil can have either negative or positive impact on their health. The major soil classification (Fig. 4c), texture (Fig. 4d), depth (Fig. 5a) and drainage (Fig. 5d) maps generated in this paper were used as criteria for the land suitability analysis.

SLOPE

The topographical condition has great impact on the evaluation and selection of surface irrigation potential zones in a given area and the gradient of land governs the method of irrigation to be implemented in the area. There is a direct relationship between slope degree and the soil depth, vulnerability to erosion, and irrigation systems. If the topographic condition of an area under consideration and the proposed sources of water cannot be directly connected by a gravity system (if elevation of source is higher than suitable land), the surface irrigation system is not feasible. A digital elevation model (DEM) of 12.5 × 12.5 m spatial resolution was used to generate slope and reclassification was made in ArcGIS version 10.4. The ranges of slope (degree) and the reclassified slope-based land suitability evaluation are presented in Figure 3a, b.

RAINFALL

Rainfall is one of climate elements which describes the hydrologic responses of a watershed to a hydrologic cycle (Scanlon, 2005; Worqlul *et al.*, 2017). Historical rainfall data for the area were considered in this analysis to map rainfall variability along the sub-basin. Accordingly, the historical point rainfall data were converted to areal with 30 × 30 m spatial resolution using the inverse distance weight (IDW) (Al-Wagdany, 2020). The rainfall intensity varies and the potential map which shows rainfall distribution and classifications of precipitation depth was analysed and presented. Rainfall distribution and corresponding slope are presented on the same map as shown in Figure 3c, d.

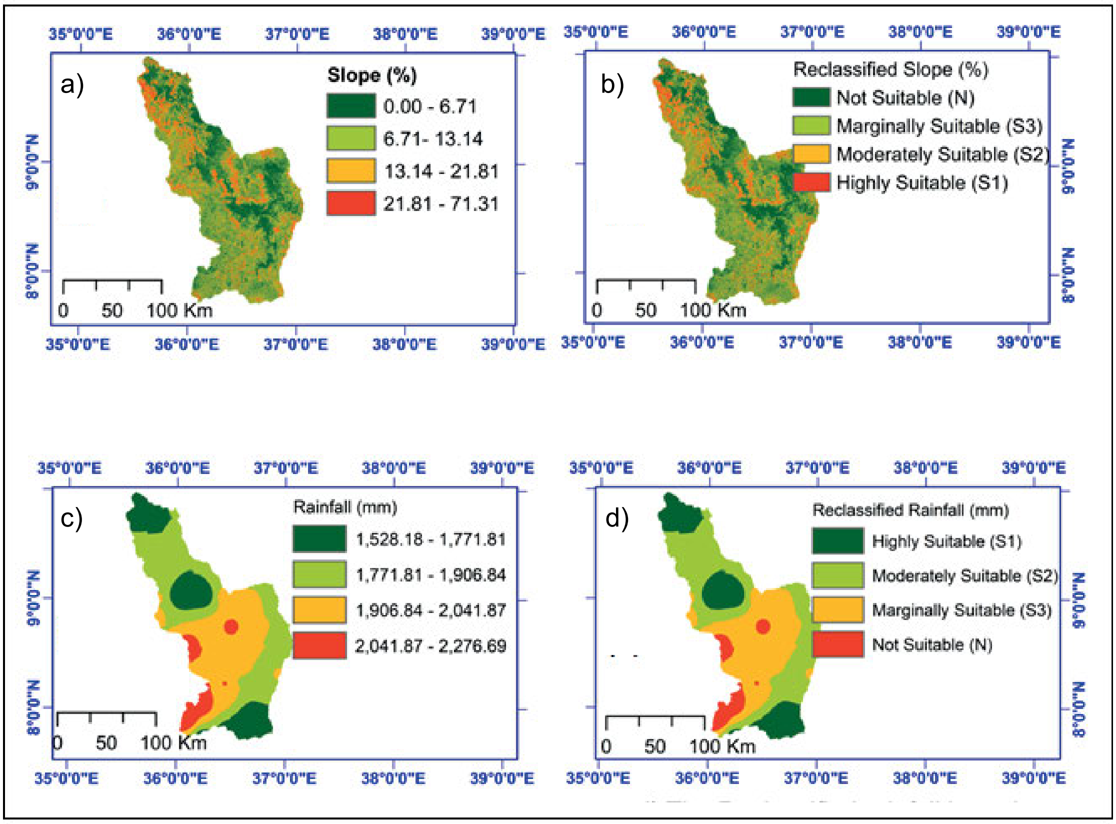

Fig. 3. Map of Didesa sub-basin: a) slope, b) reclassified slope based on surface irrigation potential zone selection, c) rainfall, d) reclassified rainfall based on surface irrigation potential zone selection: source: own study

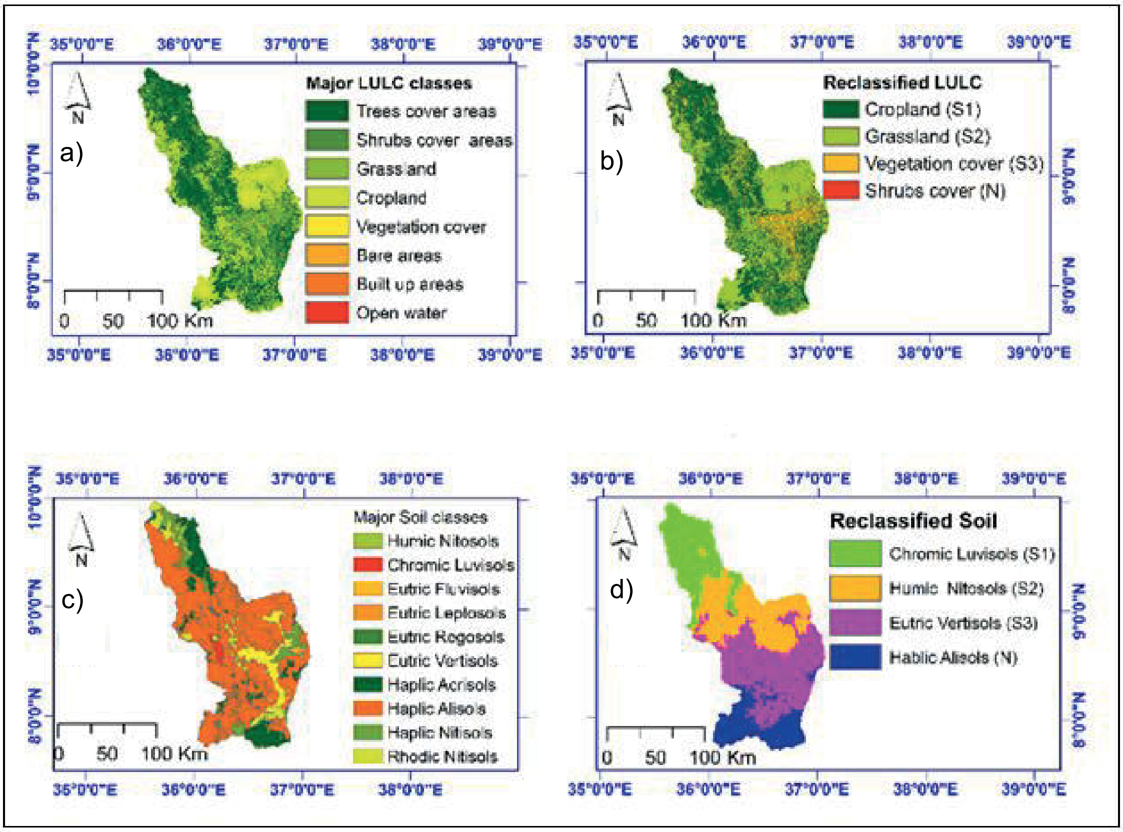

Fig. 4. Map of Didesa sub-basin: a) major land use / land cover (LULC), b) reclassified LULC based on surface irrigation potential zone selection, c) major soil classes, d) reclassified soil based on surface irrigation potential zone selection; source: own study

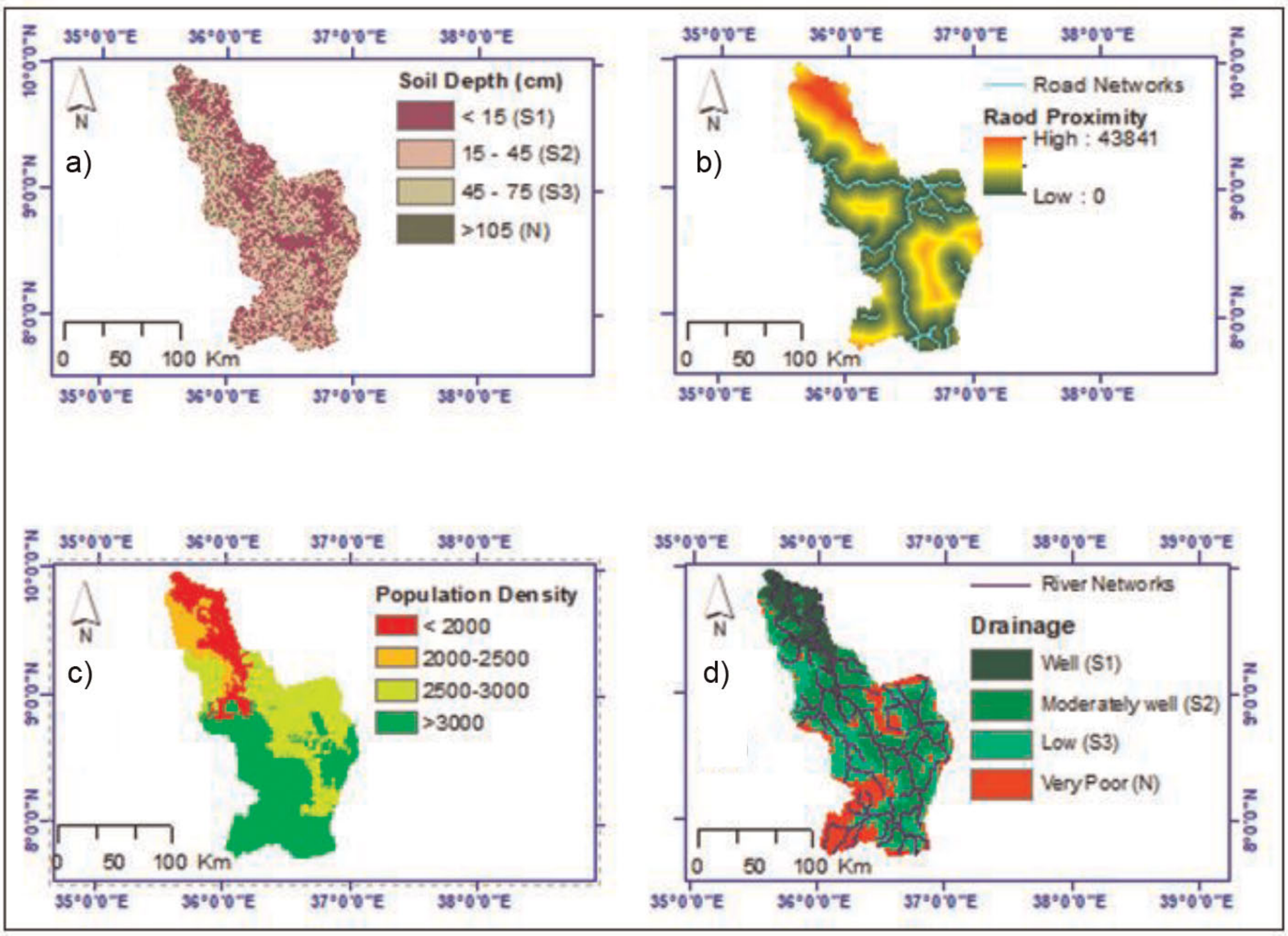

Fig. 5. Map of: a) soil depth, b) road proximity, c) population density, d) drainage; source: own study

DISTANCE

The other constraint for the exploration of surface irrigation potential zones is the distance between surface water sources and land under consideration (Worqlul *et al.*, 2017). Logically, it is acceptable that suitable and potential land should be located near surface water sources (rivers or streams), and the distance should be possibly short. Thus, the proximity analysis for the determination of the relationship between land and sources of water is important (Chuma *et al.*, 2013). The capacity of the river (whether river is perennial or not) is also evaluated, and this helps us to select appropriate structures (weir or dam) while designing and planning of an irrigation project. For this sub-basin, a distance map presented in (Fig. 5) is based on river and road networks.

POPULATION DENSITY

The 2019 census data from the Ethiopian Central Statistical Agency (CSA) was used in this study to determine population density (Worqlul *et al.*, 2019). The market and the availability of community infrastructure in the study area were integrated to evaluate the suitability of potential zones. Grid-based national census data from the CSA were overlaid with road networks and commercial centers within the study area (Al-Adamat, 2012). The population distribution is shown in Figure 5c) and it reflects the estimated number of beneficiaries in the sub-basin.

CLASSIFICATIONS OF SURFACE IRRIGATION POTENTIAL ZONES

After the key significant factors were prepared in ArcGIS 10.4 version, additional investigation was carried out for each factor for better understanding of their influence on the exploration of surface irrigation potential zones. The selection of suitable surface irrigation potential zones using the key significant factors is based on the FAO (1995) guidelines and the physical evidences collected in the catchment. The classification of the individual key factors influencing the selection of surface irrigation potential zones was reclassified into four qualitative-based classifications as high suitable (class S1), moderately suitable (class S2), marginally suitable (class S3) and not suitable (N) with detailed descriptions given in Table 3.

The map of the suitable surface irrigation potential zones in the study area involves weighting of the key significant factors. The main objective of weighing the surface irrigation potential zones is to fix the rank of each key factor comparing to other factors. The detailed steps of the analytic hierarchy process (AHP) shown in Figure 3, which is a very popular method of the multi-criteria decision analysis (MCA) technique, were used to explain the degree of importance (weights) of each key factor. The relative importance of an individual key factor is detailed in the pair-wise comparison matrix (PWCM) which rates the significance among factors concerning the exploration of surface irrigation potential zones based on the scale value ranges 1–9 as shown in Table 2.

Table 3. Land suitability classification

Class	Potential zone	Description
S1	highly suitable	land without any significant limitations
S2	moderately suitable	moderately severe limitations which reduce productivity
S3	marginally suitable	overall severe limitations; given land use is only marginally justifiable
S4	not suitable	limitations not currently overcome with existing

Source: own elaboration based on the work done by Ahmad *et al.* (2020).

The consistency of the weights derived from the pair-wise matrix should be checked and this improve the accuracy of decision making in the AHP method. The consistency of derived weights is checked by reducing the error in the estimation and this can be achieved by the consistency index (*CI*) and consistency ratio (*CR*), as shown in Equations (1) and (2).

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{1}$$

$$CR = \frac{CI}{RI} \tag{2}$$

where: $\lambda_{\max}$ = maximum eigenvalue of the pair-wise matrix, n = number of criteria used in the pairwise comparison, RI = random index for a number of an attributes used in the evaluation; the *RI* values are 0.52, 0.89, 1.11, 1.25, 1.35, 1.4, 1.45, 1.49 for the respective attributes of 3, 4, 5, 6, 7, 8, 9 and 10.

The processes of making decision about the surface irrigation potential zones in this particular study, a measurable and stepwise evaluation criterion was implemented as shown in the Figure 6. The ArcGIS 10.4 environment was used to prepare the selected key factors, and the general hierarchical framework for surface irrigation potential zone exploration implemented in this study is presented in Figure 7.

ACCURACY ASSESSMENT OF POTENTIAL ZONES

The accuracy of the multi-criteria analysis (MCA) for the exploration of surface irrigation potential zones depends on original/ground data validation. The accuracy assessment is performed by comparing identified potential zones with a reference to the remote sensing analysis. For this purpose, a hand-held Global Positioning System (GPS) field survey was conducted in the area and more than 60 points representing each land use class (total 240) points of X–Y coordinates were identified. The field survey data are supported by Google Earth Pro as a ground for the validation of potential zones. Overall accuracy (*OA*), producer accuracy (*PA*) and user accuracy (*UA*) were computed using following equations (Eqs. (3), (4) and (5)), respectively.

$$OA = \left(\frac{TNCCP}{TNCP}\right)100 \tag{3}$$

$$PA = \left(\frac{NCCC}{TNRC}\right)100 \tag{4}$$

$$UA = \left(\frac{NCCC}{TNCP}\right)100 \tag{5}$$

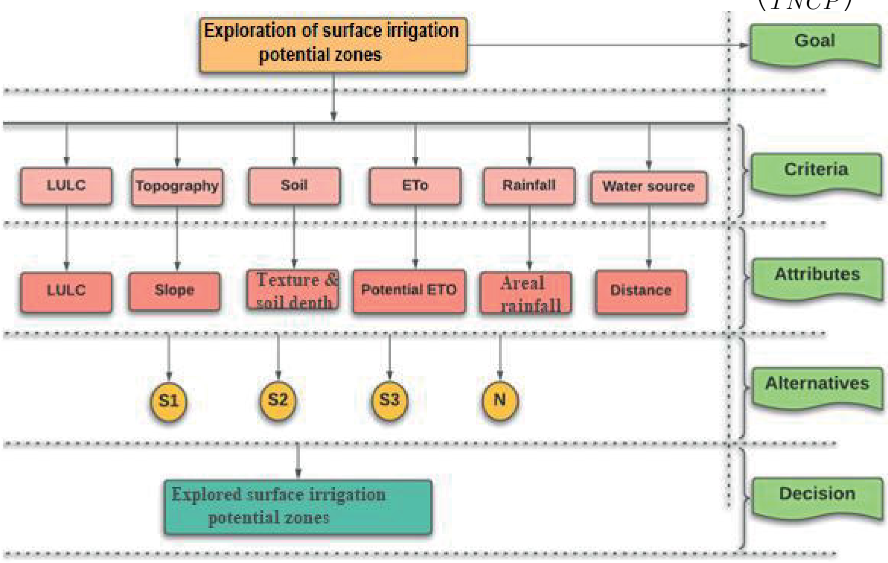

Fig. 6. Hierarchical framework of surface irrigation potential zones exploration; source: own study

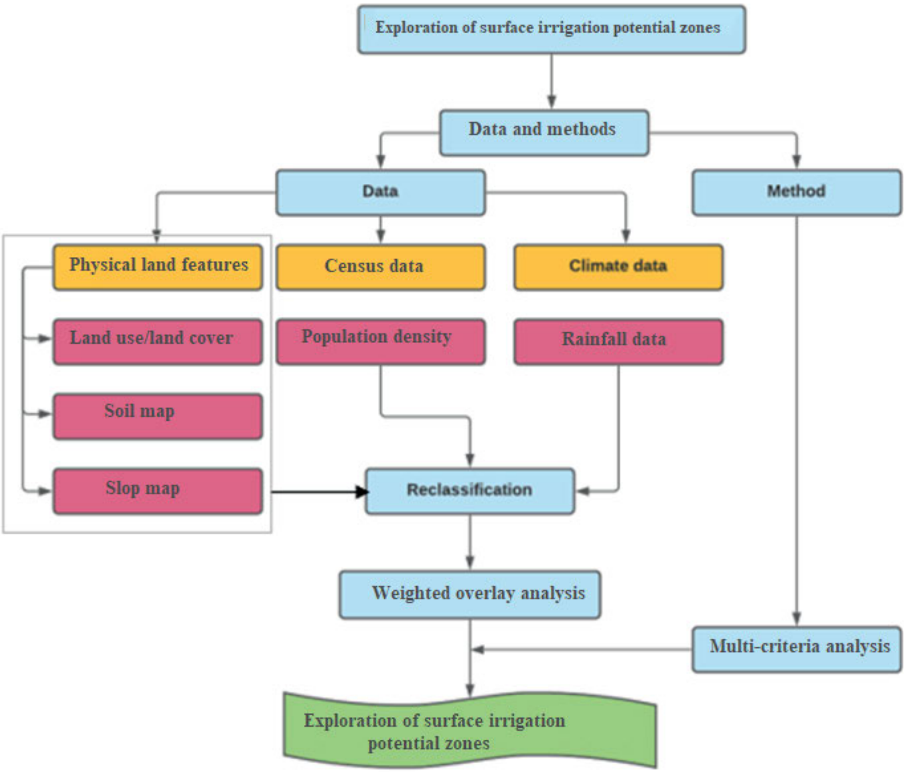

Fig. 7. Surface irrigation potential zones exploration; source: own study

where: *TNCCP* = total number of correctly classified pixels, *TNCP* = total number of classified pixels, *NCCC* = number of correctly classified class, *TNRC* = total number of references for the class.

A standard measure of accuracy for thematic classifications, such as land suitability analysis and exploration of surface irrigation potential zones, a widely used technique called kappa test is the best option. This test is used to evaluate results of the potential zones accuracy by considering all criteria (land suitability selection criteria used in this study) in confusion matrix including diagonal element and the kappa index (*KI*) is computed using predefined producer and user assigned ratings, which can be expressed as shown in Equation (6).

$$KI = \left(\frac{TS \cdot TC - \sum tot.\ sum\ of\ Rows \cdot tot.\ sum\ of\ Column}{TS^2 - \sum(tot.sum\ of\ Rows - tot.\ sum\ of\ Column}\right)100 \tag{6}$$

where: *TS* = total number of samples, *TC* = total number of samples correctly classified.

For the complete agreement value of $KI = 1$. If there is no agreement among the raters than what would be expected, the $KI \approx 1$.

RESULTS AND DISCUSSION

The principle of the pair-wise comparison matrix developed in the analytic hierarchy process (AHP) and overall weights assigned to key factors for the exploration of surface irrigation potential zones in sub-basin are summarised in Table 4. Figure 8 presents the explored surface irrigation potential zones in the Didesa sub-basin. In this sub-basin, 48.40% of the area is highly suitable, 27.26% moderately suitable, 13.27% marginally suitable and 4.91% is not suitable, and 6.16% of the area contains irrigation constraints (Fig. 9).

The importance of the key factors (LULC, soil depth, slope, texture, drainage, road proximity, *ET*, and population density) has been evaluated and weighted on the basis of their significance in the exploration of surface irrigation potential zones. The weight assigned for each key factor, the pair-wise comparison matrix, the normalised pair-wise comparison matrix and eigenvalues are presented in Tables 4 and 5. The qualitative-based results of the overall surface irrigation potential zones obtained is presented in Table 6. As we can see from Figure 9, the downstream portion of the sub-basin is highly suitable for surface irrigation practice and this will open door for the implementation of a small-scale irrigation project. The consistency of the AHP technique in capturing the exploration of surface irrigation potential zones is evaluated by consistency index (*CI*) and consistency ratio (*CR*). The summary of the consistency evaluation is presented in Table 4. As we can see from the table, the $CI > 0.1$, which indicates that weights assigned for the individual key factor in the AHP are correct (Nagaraju *et al.*, 2016; Mandal, Dolui and Satpathy, 2018; Dinka, 2020).

The key factors were arranged and evaluated based on their importance to generate the potential zones suitable for surface irrigation (Nagaraju *et al.*, 2016; Mandal, Dolui and Satpathy, 2018; Dinka, 2020). According to the result obtained in the study area, qualitative-based on classifications, namely: highly suitable, moderately suitable, marginally suitable, not suitable, and some constraints irrigation sites. These were identified and the corresponding areas of coverage is presented in Table 6. Almost similar agreement is made in the studies conducted by Mandal,

Table 4. Pair-wise comparison matrix and the key factors

Parameter	LULC	*SD*	*Sl*	*T*	*D*	*R*	*RP*	*ET*	*PD*
LULC	1.00	3.00	0.25	5.00	2.00	0.33	0.17	3.00	0.20
SD	0.33	1.00	0.50	0.33	5.00	4.00	0.13	4.00	3.00
Sl	4.00	2.00	1.00	2.00	0.25	0.33	0.33	0.20	4.00
T	0.20	3.00	0.50	1.00	0.33	0.50	2.00	3.00	8.00
D	0.50	0.20	4.00	3.00	1.00	3.00	5.00	0.14	0.33
R	0.08	0.19	0.07	0.21	0.38	1.00	0.19	0.03	0.08
RP	6.00	8.00	3.00	0.50	0.20	0.33	1.00	0.25	0.50
ET	0.33	0.25	5.00	0.33	7.00	0.20	4.00	1.00	0.17
PD	5.00	0.33	0.25	0.13	3.00	3.00	2.00	6.00	1.00
Total	**17.37**	**17.78**	**14.50**	**12.29**	**18.78**	**15.01**	**14.63**	**17.59**	**17.20**

Explanations: LULC = land use and land cover change, *SD* = soil depth, *Sl* = slope, *R* = rainfall, *T* = texture, *RP* = road proximity, *ET* = potential evapotranspiration, *PD* = population density, *D* = distance.
Source: own study.

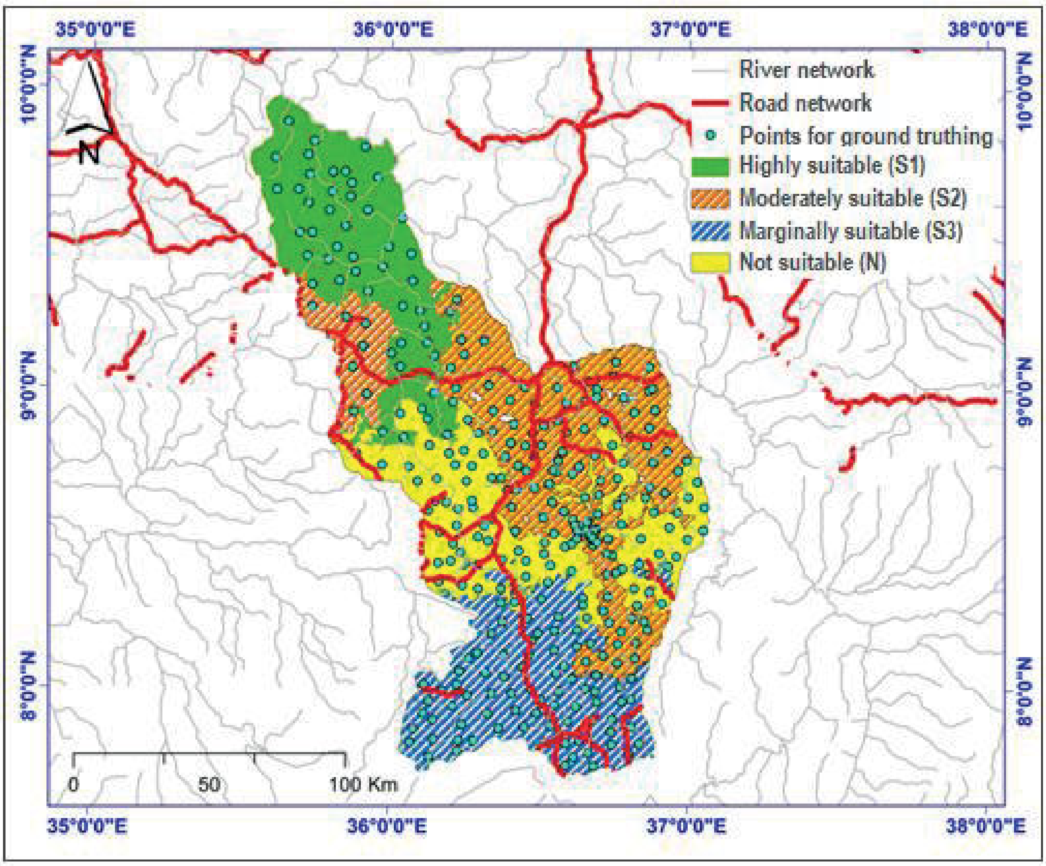

Fig. 8. Map of the explored surface irrigation potential zones; source: own study

Dolui and Satpathy (2018), Bhave, Katpatal and Pophare (2019), and Gedam Berhanu and Dagalo Hatiye (2020).

The summary of accuracy assessment with kappa index (*KI*) is presented in Table 7. As we can see from the detailed information on the computed accuracy assessment parameters, such as overall accuracy (*OA*), user accuracy (*UA*), and producer accuracy (*PA*), the kappa index (*KI*) value is 0.93. This indicates that the agreement among the raters is complete. A total number of 240 ground truth points were collected and overlaid with the potential zones generated in the MCA. Out of these points, 233 points were correctly classified in the LULC map prepared by a supervised classification and further evaluated with a base map (Fig. 10).

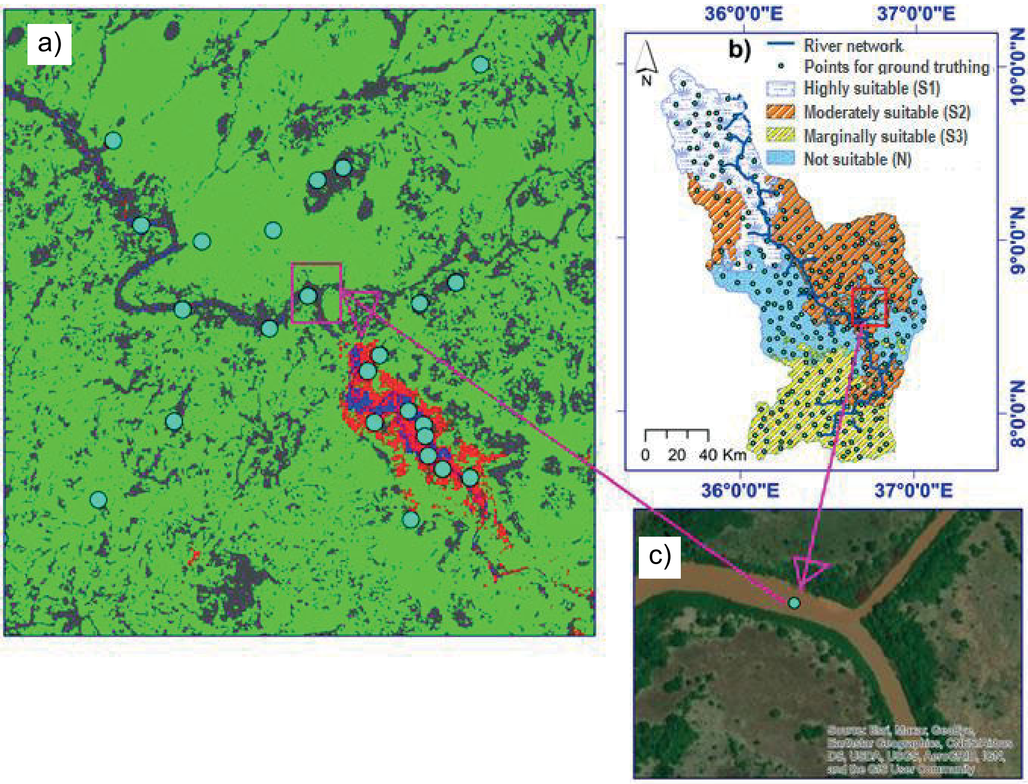

Fig. 9. Ground truth data based validated surface irrigation potential zones: a) supervised LULC classification, b) explored surface irrigation potential zones for MCA, c) base map for ground trothing for explored potential zones; source: own study

Table 5. Normalised pair-wise comparison matrix

Parameter	LULC	*SD*	*Sl*	*T*	*D*	*R*	*RP*	*ET*	*PD*	Normalised sum of rows	Normalised average rows	Eigenvector
LULC	0.06	0.17	0.02	0.41	0.11	0.07	0.01	0.17	0.01	0.95	0.95/9	0.12
SD	0.02	0.06	0.03	0.03	0.27	0.15	0.01	0.23	0.17	0.81	0.81/9	0.10
Sl	0.23	0.11	0.07	0.16	0.01	0.31	0.02	0.01	0.23	0.85	0.85/9	0.11
T	0.01	0.17	0.03	0.08	0.02	0.47	0.14	0.17	0.47	1.09	1.09/9	0.13
D	0.03	0.01	0.28	0.24	0.05	0.35	0.34	0.01	0.02	0.98	0.98/9	0.12
R	0.08	0.19	0.07	0.21	0.38	0.23	0.04	0.19	0.03	1.07	1.07/9	0.18
RP	0.35	0.45	0.21	0.04	0.01	0.01	0.07	0.01	0.03	1.17	1.17/9	0.14
ET	0.02	0.01	0.34	0.03	0.37	0.14	0.27	0.06	0.01	1.12	1.12/9	0.14
PD	0.29	0.02	0.02	0.01	0.16	0.06	0.14	0.34	0.06	1.03	1.03/9	0.13

Explanations: $\lambda = 9.125$, $n = 9$, *CI* (consistency index) = 0.017, *RI* (random index) = 1.45, *CR* (consistency ratio) = 0.01. Parameters explanations as in Tab. 4.
Source: own study.

Table 6. Overall surface irrigation potential zone classifications

Suitability class	Degree of suitability	Total area[1)] (km^2)	Percentage (%)	Excluded area[2)] (km^2)
S1	1 – highly	9,501.52	48.40	1011.64
S2	2 – moderately	5,350.88	27.26	680.17
S3	3 – marginally	2,604.42	13.27	–
N	4 – not suitable	964.79	4.91	–
Constraints	5 – irrigation constraints	1,208.39	6.16	–

[1)] Total area of land under each suitability class. [2)] Total area of land demarcated as grave and religious areas.
Source: own study.

Table 7. Accuracy assessment of surface irrigation potential zones

Suitability class	S1	S2	S3	N	1 + 2 + 3 + 4	*UA*	*PA*	Row. Tot·Col. Tot	Row. Tot – Col. Tot
	1	2	3	4	5	6	7	8	9
S1	63	0	1	0	64	98.44	96.92	997.07	33.44
S2	1	61	0	1	63	110.91	95.31	750.49	46.91
S3	0	2	55		57	90.16	105.77	807.37	34.16
N	1	1	0	54	56	90.91	98.18	201.80	35.91
Total	65	64	56	55	240			2756.7	150.42
								KI = 0.93	

Explanations: *UA* = user accuracy, *PU* = producer accuracy, S1 = highly suitable, S2 = moderately suitable, S3 = marginally suitable, and N = not suitable.
Number of surface irrigation potential zones correctly classified = 233.
Overall classification accuracy (*OA*) = (63 + 61 + 55 + 54)/240 = 233/240 = 97.08%
KI = 0.93.
Source: own study.

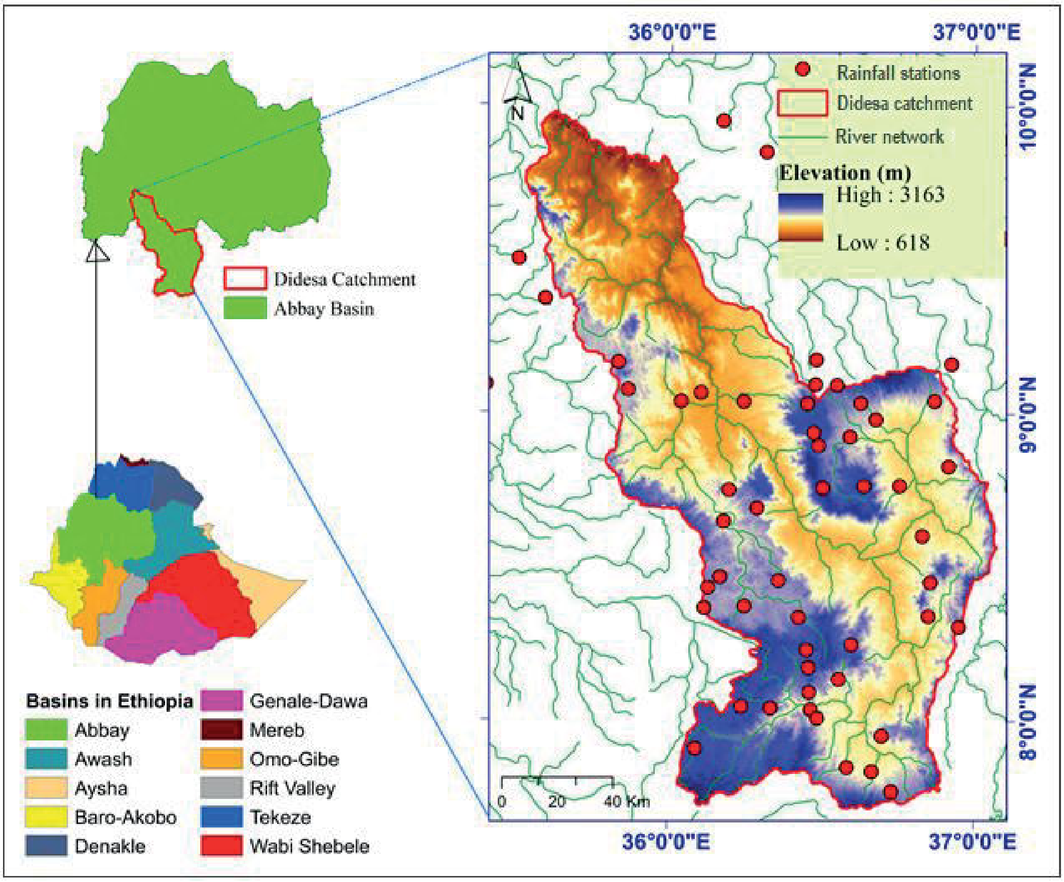

Fig. 10. Map of the Didesa sub-basin, rainfall stations, and main river networks; source: own study

CONCLUSIONS

This paper presents the application of the multi-criteria analysis (MCA) for the exploration of surface irrigation potential zones situated in the Didesa sub-basin, Ethiopia. A total of nine key significant factors, such as land use/land changes (LULC), slope, soil depth, drainage, texture, rainfall, *ET* road proximity, and population density were used to explore the surface irrigation potential zones. In this sub-basin, four areas have been designated as highly suitable (48.40%), moderately suitable (27.26%), marginally suitable (13.27%), not suitable (4.91%), and irrigation constraints (6.16%). The performance of the AHP technique for the exploration of the surface irrigation potential zones was evaluated against the consistency index (*CI* = 0.011, which is less 0.1). It was found that values of weight assigned to each factor in the MCA analysis were correct. The map of surface irrigation potential zones explored in the MCA was evaluated against the kappa index (*KI*) supported by ground truth technique. Accordingly, out of a total 240 points collected for the evaluation, 233 points were correctly classified. A supervised LULC and base maps were used to validate the potential zones generated in the MCA, and a good agreement was made with *KI* = 0.93 among the raters. In this study, the use of the multi-criteria analysis (MCA) helped to explore surface irrigation potential zones in this sub-basin. Finally, it was concluded that the results of this paper would be useful for water resources developers, residents, and entrepreneurs to intensify irrigation using the explored potential zones in the sub-basin.

REFERENCES

Abay, A. *et al.* (2017) "Determinants of prenatal anemia in Ethiopia," *Archives of Public Health*, 75(1). Available at: https://doi.org/10.1186/s13690-017-0215-7.

Abdulkadir T.S. *et al.* (2019) "Quantitative analysis of soil erosion causative factors for susceptibility assessment in a complex watershed," *Cogent Engineering*, 6(1). Available at: https://doi.org/10.1080/23311916.2019.1594506.

Ahmad, I. *et al.* (2020) "GIS-based multi-criteria evaluation for deciphering of groundwater potential," *Journal of the Indian Society of Remote Sensing*, 48(2), pp. 305–313. Available at: https://doi.org/10.1007/s12524-019-01078-3.

Akinluyi, F.O., Olorunfemi, M.O. and Bayowa, O.G. (2018) "Investigation of the influence of lineaments, lineament intersections and geology on groundwater yield in the basement complex terrain of Ondo State, Southwestern Nigeria," *Applied Water Science*, 8(1). Available at: https://doi.org/10.1007/s13201-018-0686-x.

Al-Adamat, R. (2012) "The use of GIS and Google Earth for preliminary site selection of groundwater recharge in the Azraq Oasis Area – Jordan," *Journal of Water Resource and Protection*, 04(06), pp. 395–399. Available at: https://doi.org/10.4236/jwarp.2012.46045.

Al-Nahmi, F. *et al.* (2016) "Using remote sensing for lineament extraction in Al Maghrabah area – Hajjah, Yemen," *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLII-2/W1, pp. 137–142. Available at: https://doi.org/10.5194/isprs-archives-xlii-2-w1-137-2016.

Andualem, T.G. *et al.* (2019) "Spatial assessment of groundwater quality in Guna Tana landscape," *Environmental Quality Management*, 29(2), pp. 57–66. Available at: https://doi.org/10.1002/tqem.21662.

Andualem, T.G. *et al.* (2020) "Soil erosion-prone area identification using multi-criteria decision analysis in Ethiopian highlands," *Modeling Earth Systems and Environment*, 6(3), pp. 1407–1418. Available at: https://doi.org/10.1007/s40808-020-00757-2.

Bagherzadeh, A. and Daneshvar, M.R.M. (2011) "Physical land suitability evaluation for specific cereal crops using GIS at Mashhad Plain, Northeast of Iran," *Frontiers of Agriculture in China*, 5(4), pp. 504–513. Available at: https://doi.org/10.1007/s11703-011-1102-6.

Balsubramanian, A. (2017) "Methods of groundwater exploration," *Technical Report*. Mysore: University of Mysore.

Bhave, H.D., Katpatal, Y.B. and Pophare, A.M. (2019) "Identification of ground water recharge potential zone for watershed using GIS and remote sensing," *International Journal of Advanced Research in Engineering and Technology*, 10(1). Available at: https://doi.org/10.34218/ijaret.10.1.2019.012.

Bologa, O. *et al.* (2016) "Using the Analytic Hierarchy Process (AHP) in Evaluating the Decision of Moving to a Manufacturing Process Based Upon Continuous 5 Axes CNC Machine-tools," *Procedia Computer Science*. Available at: https://doi.org/10.1016/j.procs.2016.07.171.

Chandra Bose, A.S., Giridhar, M.V.S.S. and Viswanadh, G.K. (2010) "Identification of groundwater potential zones using RS and GIS," *31st Asian Conference on Remote Sensing. ACRS–2010*, 1, pp. 327–333.

Chuma, C. *et al.* (2013) "Application of remote sensing and Geographical Information Systems in determining the groundwater potential in the crystalline basement of Bulawayo Metropolitan Area, Zimbabwe," *Advances in Remote Sensing*, 02(02), pp. 149–161. Available at: https://doi.org/10.4236/ars.2013.22019.

CEOS (no date) *International Directory Nework (IDN)*. National Aeronautics and Space Administration (NASA), I. D. N. (. 2. V. 2., 2020. *NASA*. [Online] Available at: URL: https://idn.ceos.org (Accessed: March 10, 2021).

Dar, T.A., Rai, N. and Bhat, A.A. (2020) "Delineation of potential groundwater recharge zones using analytical hierarchy process (AHP)," *Geology, Ecology, and Landscapes*, 5(4), pp. 292–307. Available at: https://doi.org/10.1080/24749508.2020.1726562.

Das, S. and Pardeshi, S.D. (2018) "Integration of different influencing factors in GIS to delineate groundwater potential areas using IF and FR techniques: a study of Pravara basin, Maharashtra, India," *Applied Water Science*, 8(7). Available at: https://doi.org/10.1007/s13201-018-0848-x.

Dawit, M. *et al.* (2020) "Impact of climate change on land suitability for the optimization of the irrigation system in the Anger River basin, Ethiopia," *Climate*, 8(9), 97. Available at: https://doi.org/10.3390/cli8090097.

Dessalegn, T.A. *et al.* (2017) "Applicability of Galway River Flow Forecasting and Modeling System (GFFMS) for Lake Tana Basin, Ethiopia," *Journal of Water Resource and Protection* [Preprint]. Available at: https://doi.org/10.4236/jwarp.2017.912084.

Desta, H. and Lemma, B. (2017) "SWAT based hydrological assessment and characterization of Lake Ziway sub-watersheds, Ethiopia," *Journal of Hydrology: Regional Studies*, 13, pp. 122–137. Available at: https://doi.org/10.1016/j.ejrh.2017.08.002.

Dibaba, W.T., Demissie, T.A. and Miegel, K. (2020) "Watershed hydrological response to combined land use/land cover and climate change in Highland Ethiopia: Finchaa Catchment," *Water*, 12(6), 1801. Available at: https://doi.org/10.3390/w12061801.

Dinka, M.O. (2020) "Quantification of soil erosion and sediment yield for ungauged catchment using the RUSLE model: Case study for Lake Basaka catchment in Ethiopia," *Lakes and Reservoirs: Research and Management*, 25(2), pp. 183–195. Available at: https://doi.org/10.1111/lre.12312.

FAO (1995) "Assessment of irrigation potential in Africa. Arc-Info: A tool for the computation on the irrigation water requirements at continental level," Rome: Food and Agriculture Organization. Available at: https://www.fao.org/3/w7320b/w7320b10.htm (Accessed: March 10, 2021).

Fayas, C.M. *et al.* (2019) "Soil loss estimation using RUSLE model to prioritize erosion control in Kelani River basin in Sri Lanka," *International Soil and Water Conservation Research*, 7(2), pp. 130–137. Available at: https://doi.org/10.1016/j.iswcr.2019.01.003.

Gebremariam, Y.B. (2010) *Geomorphological mapping in the upstreams of Muger River, using geospatial tools*. MSc Thesis. Addis Ababa: Addis Ababa University.

Gebrie, T. *et al.* (2018) "Groundwater resources evaluation using geospatial technology," *Environmental Geosciences* [Preprint]. Available at: https://doi.org/10.1306/eg.01241817010.

Gedam Berhanu, K.G. and Dagalo Hatiye, S.D. (2020) "Identification of groundwater potential zones using proxy data: Case study of Megech Watershed, Ethiopia," *Journal of Hydrology: Regional Studies*, 28, 100676. Available at: https://doi.org/10.1016/j.ejrh.2020.100676.

Ghani, A.H.A. *et al.* (2013) "Prediction of sedimentation using integration of RS, RUSLE model and GIS in Cameron Highlands, Pahang, Malaysia," *AIP Conference Proceedings*, 1571, pp. 543–548. Available at: https://doi.org/10.1063/1.4858711.

Girma, R., Gebre, E. and Tadesse, T. (2020) "Land suitability evaluation for surface irrigation using spatial information technology in Omo-Gibe River Basin, Southern Ethiopia," *Irrigation & Drainage Systems Engineering*, 9(5). Available at: https://doi.org/10.37421/idse.2020.9.245.

Hamdani, N. and Baali, A. (2020) "Characterization of groundwater potential zones using analytic hierarchy process and integrated geomatic techniques in Central Middle Atlas (Morocco)," *Applied Geomatics*, 12(3), pp. 323–335. Available at: https://doi.org/10.1007/s12518-020-00300-z.

Hammouri, N., El-Naqa, A. and Barakat, M. (2012) "An integrated approach to groundwater exploration using remote sensing and Geographic Information System," *Journal of Water Resource and Protection*, 04(09), pp. 717–724. Available at: https://doi.org/10.4236/jwarp.2012.49081.

Hategekimana, Y. *et al.* (2020) "Quantification of soil losses along the coastal protected areas in Kenya," *Land*, 9(5), 137. Available at: https://doi.org/10.3390/land9050137.

Iticha, B. and Takele, C. (2019) "Digital soil mapping for site-specific management of soils," *Geoderma*, 351, pp. 85–91. Available at: https://doi.org/10.1016/j.geoderma.2019.05.026.

Kayet, N. *et al.* (2018) "Evaluation of soil loss estimation using the RUSLE model and SCS-CN method in hillslope mining areas," *International Soil and Water Conservation Research*, 6(1), pp. 31–42. Available at: https://doi.org/10.1016/j.iswcr.2017.11.002.

Lange Salvia, A.L. *et al.* (2019) "An analysis of the applications of Analytic Hierarchy Process (AHP) for selection of energy efficiency practices in public lighting in a sample of Brazilian cities," *Energy Policy*, 132, pp. 854–864. Available at: https://doi.org/10.1016/j.enpol.2019.06.021.

Mandal, B., Dolui, G. and Satpathy, S. (2017) "Land suitability assessment for potential surface irrigation of river catchment for irrigation development in Kansai watershed, Purulia, West Bengal, India," *Sustainable Water Resources Management*, 4(4), pp. 699–714. Available at: https://doi.org/10.1007/s40899-017-0155-y.

Maqsoom, A. *et al.* (2020) "Geospatial assessment of soil erosion intensity and sediment yield using the Revised Universal Soil Loss Equation (RUSLE) model," *ISPRS International Journal of Geo-information*, 9(6), 356. Available at: https://doi.org/10.3390/ijgi9060356.

Melak S. (2007) *Land capability, irrigation potential and crop suitability analysis using GIS and Remote Sensing in Upper Kesem (Awash Basin)*. MSc Thesis. Addis Ababa: Addis Ababa University.

Mideksa, G. and Temesgen, T. (2020) "Irrigation water potential and land suitability assessment in Kurfa Chele," *Turkish Journal of Agriculture – Food Science and Technology*, 8(1), pp. 139–146. Available at: https://doi.org/10.24925/turjaf.v8i1.139-146.2863.

Nagaraju, A. *et al.* (2016) "Integrated approach using remote sensing and GIS for assessment of groundwater quality and hydrogeomorphology in certain parts of Tummalapalle Area, Cuddapah District, Andhra Pradesh, South India," *Advances in Remote Sensing*, 05(02), pp. 83–92. Available at: https://doi.org/10.4236/ars.2016.52007.

NASA Earth Data (no data) *ASF Data Search Vertex*. Available at: https://search.asf.alaska.edu/#/ (Accessed: March 15, 2021).

Nosal, K. and Solecka, K. (2014) "Application of AHP method for multi-criteria evaluation of variants of the integration of urban public transport," *Transportation Research Procedia*, 3, pp. 269–278. Available at: https://doi.org/10.1016/j.trpro.2014.10.006.

Olika, G. and Iticha, B. (2019) "Assessment of soil erosion using RUSLE and GIS techniques: A case of Fincha'a Watershed, Western Ethiopia," *American-Eurasian Journal of Agricultural & Environmental Sciences*, 19(1), pp. 31–36. Available at: https://doi.org/10.5829/idosi.aejaes.2019.31.36.

Panagos, P. *et al.* (2018) "Cost of agricultural productivity loss due to soil erosion in the European Union: From direct cost evaluation approaches to the use of macroeconomic models," *Land Degradation & Development*, 29(3), pp. 471–484. Available at: https://doi.org/10.1002/ldr.2879.

Paola de, F. *et al.* (2014) "Intensity-Duration-Frequency (IDF) rainfall curves, for data series and climate projection in African cities," *SpringerPlus*, 3(1). Available at: https://doi.org/10.1186/2193-1801-3-133.

Payne, S., Magruder, I.A. and Woessner, W. (2013) "Application of a Groundwater Classification System and GIS Mapping System for the Lower Ruby Valley Watershed, Southwest Montana," *Journal of Water Resource and Protection*, 05(08), pp. 775–791. Available at: https://doi.org/10.4236/jwarp.2013.58079.

Pimentel, D. and Burgess, M.M. (2013) "Soil erosion threatens food production," *Agriculture*, 3(3), pp. 443–463. Available at: https://doi.org/10.3390/agriculture3030443.

Prasannakumar, V. *et al.* (2012) "Estimation of soil erosion risk within a small mountainous sub-watershed in Kerala, India, using Revised Universal Soil Loss Equation (RUSLE) and geo-information technology," *Geoscience Frontiers*, 3(2), pp. 209–215. Available at: https://doi.org/10.1016/j.gsf.2011.11.003.

Raviraj, A., Kuruppath, N. and Kannan, B. (2017) "Identification of potential groundwater recharge zones using Remote Sensing and Geographical Information System in Amaravathy Basin," *Journal of Remote Sensing & GIS*, 6(4), pp. 1–10. Available at: https://doi.org/10.4172/2469-4134.1000213.

Saad Al-Wagdany, A. (2020) "Intensity-duration-frequency curve derivation from different rain gauge records," *Journal of King Saud University – Science*, 32(8), pp. 3421–3431. Available at: https://doi.org/10.1016/j.jksus.2020.09.028.

Saitaptim, S. (2011) *Waste water treatment of recycling industry by algae for producing biodiese* [In Thai] [Online]. Bangkok: National Institute of Development Administration Available: http://library1.nida.ac.th/termpaper6/sd/2554/19755.pdf (Accessed: March 15, 2021).

Scanlon, B.R. *et al.* (2005) "Impact of land use and land cover change on groundwater recharge and quality in the southwestern US," *Global Change Biology*, 11(10), pp. 1577–1593. Available at: https://doi.org/10.1111/j.1365-2486.2005.01026.x.

Thapa, P. (2020) "Spatial estimation of soil erosion using RUSLE modeling: A case study of Dolakha district, Nepal," *Environmental Systems Research*, 9(1), 15. Available at: https://doi.org/10.1186/s40068-020-00177-2.

Tolche, A.D. (2020) "Groundwater potential mapping using geospatial techniques: a case study of Dhungeta-Ramis sub-basin, Ethiopia," *Geology, Ecology, and Landscapes*, 5(1), pp. 65–80. Available at: https://doi.org/10.1080/24749508.2020.1728882.

USBR TSC (2005) "Technical guidelines for irrigation suitability land classification," [Online]. Denver: U.S. Department of the Interior, Bureau of Reclamation Technical Service Center. Available at: https://www.usbr.gov/tsc/techreferences/mands/mands-pdfs/TechnicalGuidelinesForIrrigationSuitabilityLandClass_2005.pdf (Accessed: March 15, 2021).

Worqlul, A.W. *et al.* (2017) "Assessing potential land suitable for surface irrigation using groundwater in Ethiopia," *Applied Geography*, 85, pp. 1–13. Available at: https://doi.org/10.1016/j.apgeog.2017.05.010.

Worqlul, A.W. *et al.* (2019) "Effect of climate change on land suitability for surface irrigation and irrigation potential of the shallow groundwater in Ghana," *Computers and Electronics in Agriculture*, 157, pp. 110–125. Available at: https://doi.org/10.1016/j.compag.2018.12.040.

Yan, R. *et al.* (2018) "Estimating soil erosion response to land use/cover change in a catchment of the Loess Plateau, China," *International Soil and Water Conservation Research*, 6(1), pp. 13–22. Available at: https://doi.org/10.1016/j.iswcr.2017.12.002.

Yulianto, F. *et al.* (2020) "Spatial-temporal dynamics land use/land cover change and flood hazard mapping in the Upstream Citarum watershed, West Java, Indonesia," *Quaestiones Geographicae*, 39(1), pp. 125–146. Available at: https://doi.org/10.2478/quageo-2020-0010.