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Research Article

Geospatial technology with the integration of MCDA to identify potential irrigation sites for agricultural land management in Wanka watershed, Northwestern Ethiopia

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Abstract

Irrigation improves the productivity of agriculture in any country. Irrigation is viewed as a fundamental approach to ensure food security, improve crop productivity, income of smallholder farmers, ensure food security, alleviate poverty and improve the economy of the farming community by generating additional income. As a result, the goal of this study was to identify prospective irrigated lands for agricultural land management in the Wanka watershed in northwestern Ethiopia using geospatial technology and multi-criteria decision-making analysis. Identifying sites for surface irrigation for agricultural land management is not a simple task, which needs consideration of many criteria such as slope, soil texture, soil depth, soil drainage, land use/land cover and distance from the water supply were used to determine the best possible location. Each factor was categorized into highly suitable, moderately suitable, marginally suitable and currently not suitable. The final result showed that the watershed had a high opportunity for surface irrigation. About 498 km^2 of the watershed's total area is potentially suitable for surface irrigation, whereas the remaining 443 km^2 is not. In the research area, there is sufficient land area accessible for surface irrigation development if those locations with highly suitable to marginally suitable areas are properly utilized.

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Introduction

Water is recognized as the most significant factor in transforming low-productivity rainfed agriculture into the most efficient irrigated agriculture (FAO, 1996; Melak, 2007; Tesfaye et al., 2008; Teka et al., 2010). Surface irrigation is a system that delivers water to crops using gravity. It is the most common form of irrigation and has been practiced for thousands of years throughout the world (Worqlul et al., 2017; Ahmed, 2019; Nasir et al., 2019). Irrigation development has great potential to advance productivity and minimizes vulnerability to climate volatility (Awulachew et al., 2007; Eshetu and Young, 2017). Water resource management receives particular attention due to a lack of water storage and wide spatial and temporal fluctuations in rainfall, declining landholding size, increasing landlessness, environmental degradation, subsistence and rainfed agriculture, and environmental degradation (Eshetu and Young, 2017; Taghvaeian et al., 2018).

Agriculture is Ethiopia's most important economic activity (Hailu and Quraishi, 2017; Tefera and Cho, 2017; Nasir et al., 2019) and employs around 80% of the workforce, 28% of tax revenue, 70% of the supply of raw materials, 40% of GDP and 85% of revenue (MoFED, 2012; Kebede and Ademe, 2016). However, the agricultural industry in Ethiopia is still traditional (Girma et al., 2019) and most of the cultivated land in Ethiopia is under rainfed agriculture, which is frequently prone to rainfall variability (Worqlul et al., 2017; Tukura and Feyissa, 2020). Ethiopia cannot achieve food security through rainfed agriculture alone, and the country receives food aid for about 10% of the population at risk each year (Makombe et al., 2007; Hailu and Quraishi, 2017). Therefore, alternative ways to improve agricultural production is needed (Kebede and Ademe, 2016).

Ethiopia has a large irrigation potential based on accessible land and water resources (122 billion m^3 surface water and 40 billion m^3 groundwater source and 3.7 million hectares (Negash and Seleshi 2004; Awulachew et al., 2007). Only roughly 190,000 hectares (5.3 percent of the potential) are irrigated, and irrigation development in the country is still in its infancy (MoWE, 2012; Sultan, 2013; Kebede and Ademe, 2016). The per capita irrigated area of Ethiopia is about $30m^2$. This value is very small compared to the $450m^2$ global average (Awulachew et al., 2007). As a result, it is important that significant attention be given to enhance irrigated agriculture and bring food security (Awulachew et al., 2007), and stimulating economic growth and rural development (MoWR 2002).

Evaluating and appraising irrigation site potential and suitability ensures the long-term economic feasibility and sustainability of water resource development (Kebede and Ademe, 2016). Wanka watershed is gifted with enormous surface water resources with a large portion of plain topography. Despite this fact, the area cultivating crops only during the rainy season. According to (Bodaghabadi et al., 2015; Girma et al., 2020), to properly manage land resources, a land suitability evaluation is frequently conducted to evaluate which location is appropriate for a particular use. Therefore, to bring food security, improved diets, improve crop productivity and income of smallholder farmers in the study area, development and expansion of irrigation infrastructure and agriculture should be seriously considered (Domènech, 2015; Kebede and Ademe, 2016; Wakeyo and Gardebroek, 2017; Sema et al., 2020). In recent years, integration of geographic information systems and multi-criteria decision making has been used for site selection studies (Babalola and Busu, 2011; Uyan, 2013; Wale et al., 2013; Watson and Hudson, 2015; El Maguiri et al., 2016; Anwarzai and Nagasaka, 2017; Baseer et al., 2017; Gheshlagi and Feizizadeh, 2017; Feizizadeh and Kienberger, 2017; Maleki et al., 2017; Ejegu and Yegizaw, 2020). Therefore, the main goal of this study was to use GIS and MCDA to find a possibly acceptable site for surface irrigation in the Wanka watershed.

Materials and Methods

Study area

Wanka watershed is located in Amhara National Regional State of Ethiopia. Geographically, it is located between 11 ° 12 '- 11 ° 43' N and 37 ° 54 '- 38 ° 15' E. The elevation varies from 1296 to 4104 meters above sea level and the peak point is found in Mount Guna, which is the source of numerous rivers. The total area of the watershed is 941 km^2. The mean annual precipitation of the study area over the last 30 years (1990 to 2019) is 1400 mm. The watershed is the tributaries of the Blue Nile (Figure 1).

Dataset

Identifying potential sites of surface irrigation for agricultural land management using geospatial technology with the integration of MCDA is the main strategy to minimize poverty, ensure food security and improve the community economy. Both primary and secondary data sources were used to achieve the objective of the study. Sentinel-2 satellite image of 2020 with a resolution of 10 meters blue, green, red and NIR bands were used to prepare land use/land cover map and ASTER DEM was used to generate a slope map through ERDAS imagine 2015. River and soil data from the Ethiopia Ministry of Water Resource were extracted and pre-processed using geospatial software packages. All layers are projected into UTM zone 37N and converted into a raster data structure.

Criteria for surface irrigation identification

Site selection is a complex process that requires taking many contradictory criteria into account at the same time. Factors that determine the location of the surface irrigation were identified based on literature, slope, soil depth, soil texture, soil drainage, land use/land cover and distance from water supply were used to identify the best possible location and each factor was classified as highly suitable, moderately suitable, marginally suitable and not suitable (FAO, 1997; Teka et al., 2010; Kebede and Ademe, 2016; Muema, 2016; Hailu and Quraishi, 2017; Worqlul et al., 2017; Girma et al., 2019; Nasir et al., 2019 Girma et al., 2020) (Table 1).

Multi-criteria decision analysis for surface irrigation

To determine suitable site for surface irrigation areas in Wanka watershed, a Multi-Criteria Decision Analysis (MCDA) was used. The first issue in MCDA is how to combine the data from several sources (Wale et al., 2013). MCDA is a tool that allows people to choose the best option from many criteria (Muema, 2016).

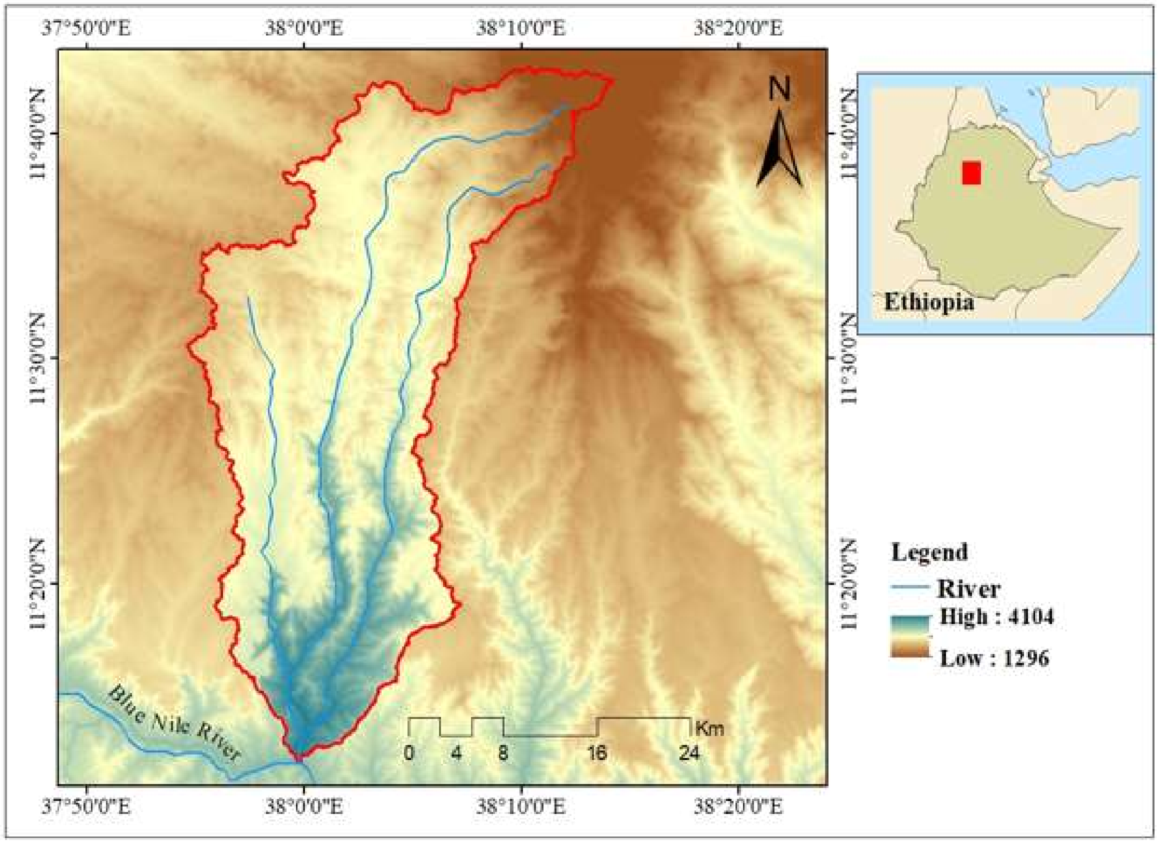

Figure 1. Map of Wanka Watershed.

Table 1. Criteria and data used.

Criteria	S_1	S_2	S_3	N	Source
Soil drainage	Well	Moderate	Imperfect	Poor to Very poor	FAO, 1997; Muema, 2016; Girma et al., 2020
Soil depth (cm)	>100	80-100	50-80	<50	FAO 1997; Kebede and Ademe, 2016; Hailu and Quraishi, 2017
Soil texture	L-SiCL, C	SiL, SCL	SL	-	FAO, 1997; Muema,2016
Slope (%)	0-2	2-5	5-8	>8	Kebede and Ademe, 2016; Hailu and Quraishi, 2017; Nasir et al., 2019; Girma et al., 2020
LULC	Cultivated land	Grassland	Bareland	Forest, built up wetland, water	Girma et al., 2020
River proximity	<1	1-3	3-4	>4	Girma et al., 2019

The importance of each variable in the irrigation potential was used to calculate the weighting of the decision criteria (Melak, 2007). The percentage influence and rating of suitability class were calculated by pairwise weighting according to Satty (1977). Pairwise comparison, which was applied as in the analytical hierarchy process technique, was used to determine the values of each of these criteria. The consistency ratio (CR) was calculated to control the consistency of the predicted weight values, and the CR values of all comparisons were 0.03, indicating that the weights were appropriate.

Results and Discussion

Slope

Based on (FAO, 1997; Girma et al., 2020) classification system, the results presented in Figure 2a revealed that 275.34km^2 (29.26%) are highly suitable, 195.46 km^2 (20.77%) moderately suitable, 194.37 km^2 (20.65%) marginally suitable and 275.83 km^2 (29.32%) is not recommended for the implementation of surface irrigation. The slope is one of the main important aspects in evaluating a land property for irrigation since it influences production and development costs (Hailu and Quraishi, 2017). It has influenced runoff, drainage, erosion, and irrigation type selection, which is crucial for soil development and management (FAO, 1997; Fasina, 2008; Nasir et al., 2019). Low slope areas have a greater opportunity for irrigation because the flat surface is easier to build canals (Fasina, 2008). The risk of soil loss due to erosion increases with slope (Muema, 2016; Hailu and Quraishi, 2017). Furthermore, as the terrain becomes steeper, a greater percentage of water is lost as runoff and climb water to the higher slope is also difficult (Girma et al., 2020).

Soil depth

The result shown in Figure 2b indicates that 590.56 km^2 (62.76%) of the total area of Wanka watershed is highly suitable and the remaining parts of 218.24 km^2 (23.19%) are moderately suitable and 132.20 km^2 (14.05%) are not suitable. A soil depth controls the germination and growth of plants and also determines the amount of water in the soil and the supply of nutrients available to the plants (Napier and Hill, 2012; Hailu and Quraishi, 2017).

Soil texture

As shown in Figure 2c, 846.37 km^2 (89.94%) of land is ideal for surface irrigation, while 94.63 km^2 (10.06%) is moderately suitable, which indicates that soil texture is not the major problem for surface irrigation. Soil texture determines the pore spaces in the soil that influence soil permeability, infiltration rate, water holding capacity, and as a result, its value for surface irrigation (Alberta, 2004; Ahmadi et al., 2011).

Soil drainage

As the results show (Figure 3a), about 552.51 km^2 (58.71%) of Wanka watershed is highly suitable, 344.30 km^2 (36.59%) is moderately suitable, 33.23 km^2 (3.53%) is marginally suitable and 10.96 km^2 (1.17%) is not suitable for surface irrigation. One of the most essential soil features that influences plant growth, water transfer, and solute transport in soils is soil drainage (Kiliccedil, 2009). It is significant because it regulates the flow of water and salt through the soil profile (Hailu and Quraishi, 2017). Without this, salt levels could rise to the point where they are damaging to plants (Alberta, 2004).

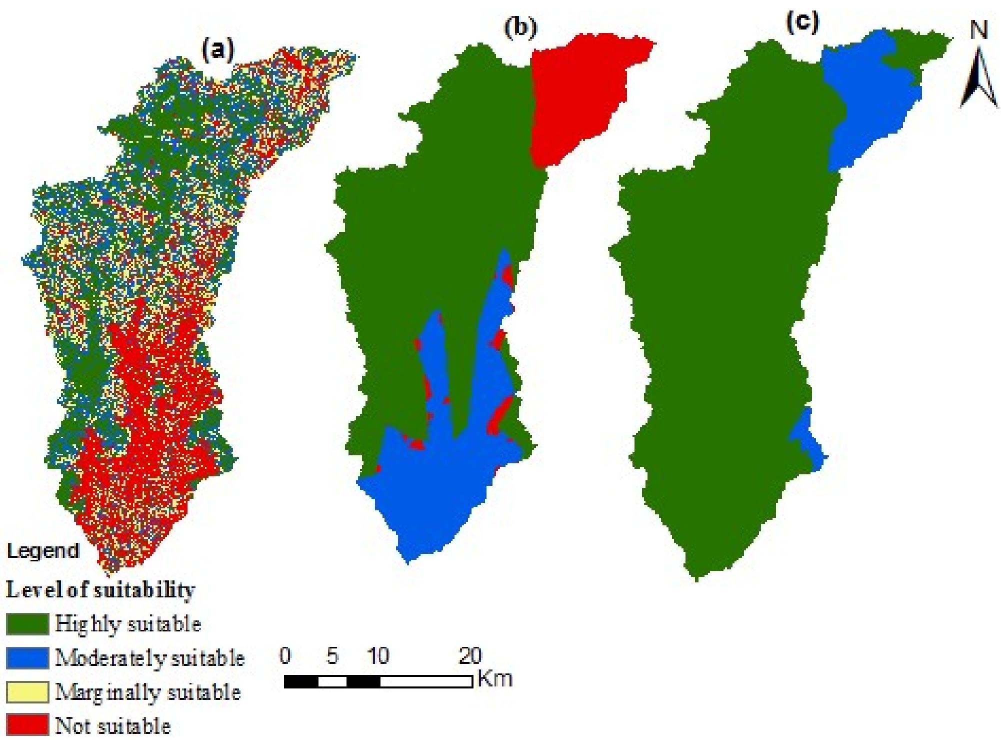

Figure 2. Suitability classes of (a) slope, (b) soil depth and (c) soil texture.

Land use/land cover

As shown in Figure 3b, cultivated land covers 623 km^2 (66.21%) of the watershed. Grassland is classified as moderately suitable for irrigation and covers 35 km^2 (3.72%). 23 km^2 (2.44%) is classified as marginally suitable. While forest land, built up and water bodies are categorized as not suitable for irrigation and they represent 260 km^2 (27.63%) of the total area of the study area. According to Meron (2007), Hailu and Quraishi (2017), Girma et al. (2019), cultivated land was rated as highly appropriate for surface irrigation with the idea that these types of land cover could be irrigated without limitation.

Distances to the water source

Irrigated land should be located as close as to rivers to economically develop the irrigation canal (Muema, 2016; Girma et al., 2020). The result shown in Figure 3c indicates that 548.75 km^2/58.32% of the land is found at a distance of 1 km from water sources, while 201.04 km^2 (21.36%) categorized as moderately suitable, 171.63 km^2 (18.24%) marginally suitable and 19.58 km^2 (2.08) of land are not suitable for surface irrigation.

Weighted overlay analysis

Weighted overlay analysis is applied to solve the multi-criteria problem and identify the most suitable site for the development of surface irrigation. The criteria were river proximity, LULC, slope, soil drainage and soil texture are applied weighted in AHP 30%, 20%, 19%,14%, 10%, and 7%, respectively.

Suitable site

The study area's final map revealed that the watershed had a vast area suitable for surface irrigation. About 52.92 percent of the watershed's total area was possibly suitable for surface irrigation. Of potentially suitable land for irrigation, 7.01% was very suitable, 19.87% was moderately suitable, while 26.04% of the Wanka watershed is considered marginally suitable. The remaining 47.08% was not suitable. (Figure 4 and Table 2).

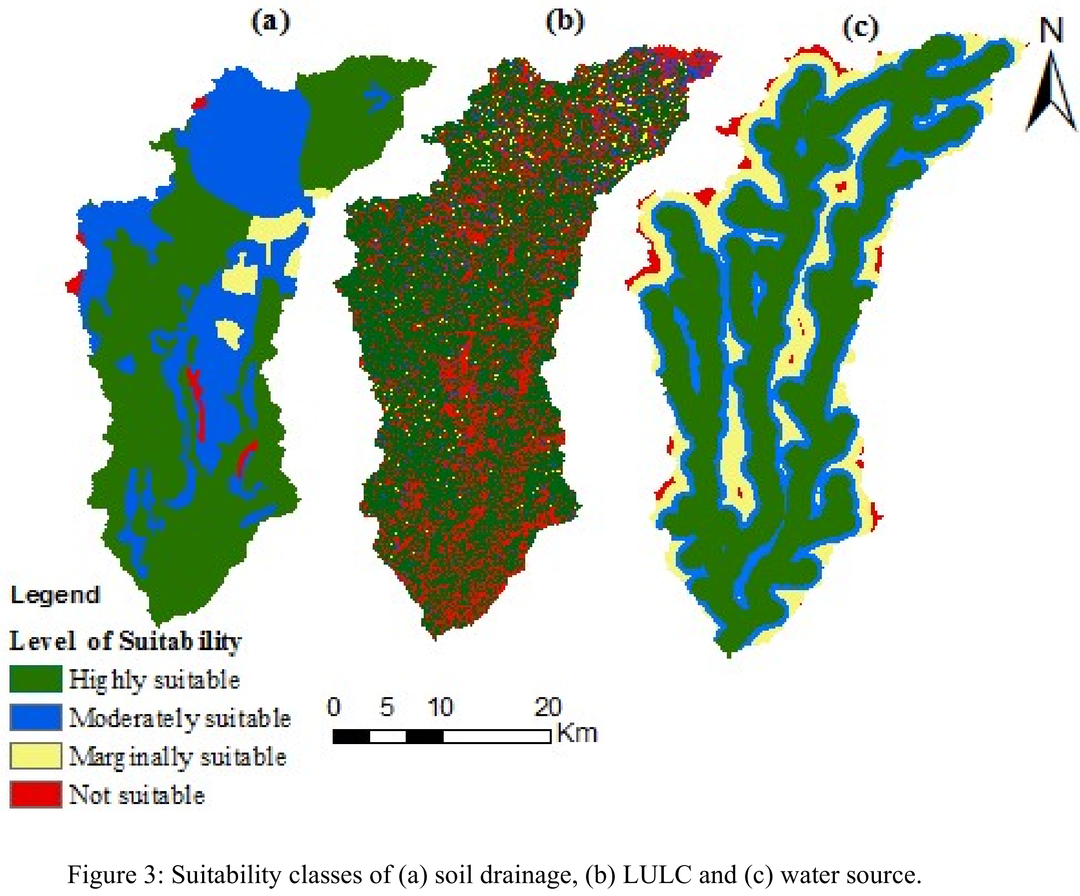

Figure 3: Suitability classes of (a) soil drainage, (b) LULC and (c) water source.

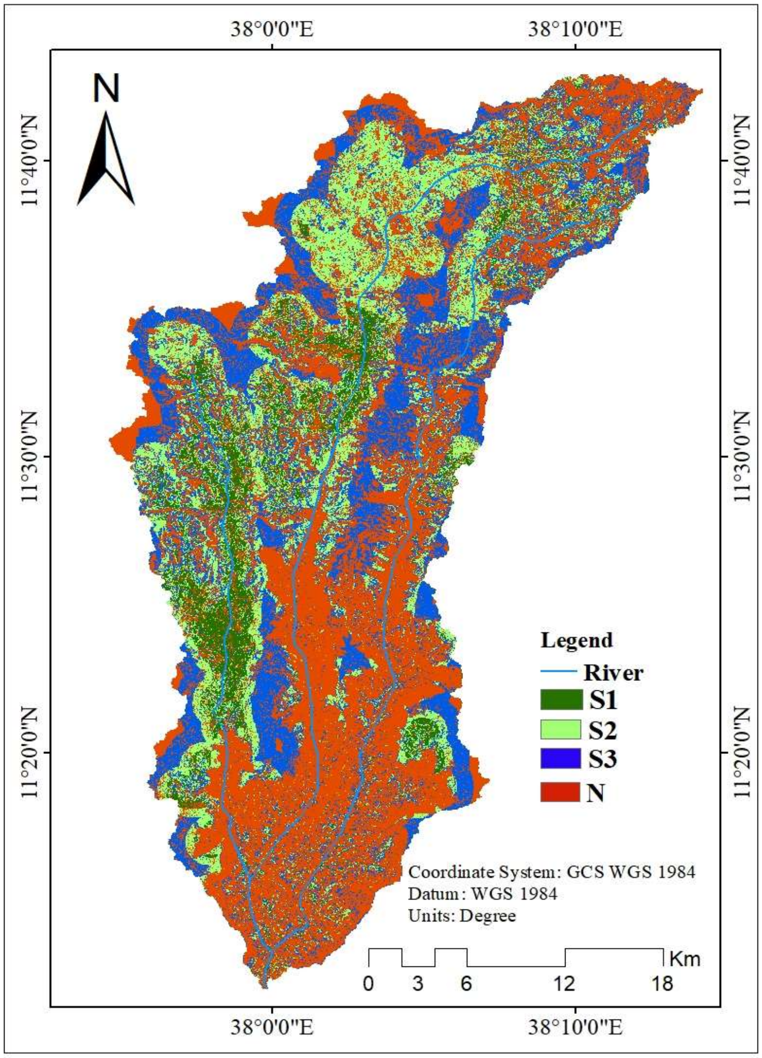

Figure 4. Suitable site in the Wanka basin.

Table 2. Suitability classes and land areas for surface irrigation.

No	Suitability Class	Area (km^2)	Percent (%)
1	Highly suitable	66	7.01
2	Moderately suitable	187	19.87
3	Marginally suitable	245	26.04
4	Not suitable	443	47.08
	Total	941	100

Conclusion

The global water crisis has got worldwide attention to achieving more efficient use of water resources for agriculture to increase food production and achieve food security. Irrigation provides farmers with sustained livelihoods, improve their nutritional outcomes and general well-being through increased productivity and availability of food supplies. The application of MCDA with GIS for surface water irrigation site selection in Wanka watershed, Northwestern Ethiopia, by taking soil texture, soil drainage, soil depth, slope, land use/land cover, and distance from water sources can solve large and conflicting criteria in surface irrigation site selection processes and sufficient land area available for surface irrigation development in the study area.

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