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GIS based multi-criteria decision-making approach for dry port location analysis: The case of Ethiopia[☆]

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ABSTRACT

Dry port construction facilitates intermodal freight transport in the import and export corridors, especially for landlocked countries. Selecting the optimal locations for dry ports is a crucial component of national planning. In this study, multi-criteria decision-making (MCDM) combined with GIS was used to map suitable sites for dry ports. Essential criteria for selecting optimum dry port locations were identified from the literature and a Simple Multi-Attribute Ranking Technique (SMART) was used for expert weighting these criteria. The results revealed that distance from road and distance from railway are the two most important criteria, while distance from a seaport is the least important. Application of the method to identify optimal dry port locations in Ethiopia showed that most of its territory is moderately suitable for dry port location. However, most of the existing dry ports in the region are found to lie within the highly suitable areas. Overall, the suitability map developed in this study provides a rich basis of information for future sustainable dry port investments.

1. Introduction

As global trade expands, inefficiencies in seaports pose challenges, which dry ports can help mitigate by providing support to seaport operations from within the port hinterland (Roso et al., 2009; Rodrigue & Notteboom, 2012; Awad-Núñez et al., 2016). Dry ports can play a significant role in alleviating efficiency and environmental concerns as they are an integral part of an intermodal freight transport system, enriching the traditional hinterland concept (Van Arjen Klink & Van Den Berg, 1998; Roso et al., 2009; Kurtuluş, 2023). A dry port is an inland terminal performing seaport activities and is directly linked to the seaport using inland transport, mainly rail (Nguyen & Notteboom, 2016; Roso et al., 2015). 'Dry port' is used interchangeably with terms such as inland terminal, inland port, inland container depot (ICD) and logistics centre (Özceylan, Erbaş, Tolon, Kabak, & Durłut, 2016; Nguyen & Notteboom, 2019). The dry port concept has some distinct advantages for landlocked countries, which tend to suffer more from seaport-related challenges than coastal countries, due to their restricted access to seaports.

A proper placement of a dry port is essential to meet its purposes and benefits (Rodrigue & Notteboom, 2012). Various performance indicators of dry ports such as safety, time, accessibility and sustainable measurement are a function of their location (Beyene, Nadeem, & Jaleta, 2024; Roso et al., 2015). Moreover, choosing the optimal location for dry ports is also crucial in ensuring an efficient logistics and transport system, impacting the entire supply chain. The wrong placement of such infrastructure may result in capital losses and economic instability of the facility (Ng & Cetin, 2012). Dry port development is still in its early stages in developing economies, leading to limited integration and performance challenges (Jeevan et al., 2022). Hence, deploying a robust location analysis approach to identify optimal dry port locations has become as a significant area of research.

The location analysis concept is a centuries-old research matter broadly applied in various fields (ReVelle, Eiselt, & Daskin, 2008). In many studies candidate sites or areas for sites are chosen randomly, with some notable exception works of Chang, Notteboom, and Lu (2015),

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Abbasi and Pishvaee (2018) and Santos & Machado, 2020. However, for evaluations in developing countries, a techniqueis required to guid decision makers, often government bodies in these economies, in the absence of predefined locations. This will help address lack of a holistic framework to locate dry ports, imbalance in their use and their low performance in developing economies (Ng & Cetin, 2012; Nguyen & Notteboom, 2016; Nitsche, 2021). Weightings reflecting the priorities considered when selecting dry port locations in these economies is necessary. Additionally, we are not aware of other studies evaluating the existing locations with respect to their parametrically determined suitability. Therefore, in the present study, we propose an easily operable method to create a comprehensive suitability map for dry port locations in a large geographical area. We develop the suitability map for the case of Ethiopia and provide an extensive interpretation of results. As a large and landlocked country with a growing economy, studies focused on planning dry ports are essential for Ethiopia. Additionally, the government aims to explore the use of seaports in other neighbouring countries, highlighting the importance of effective dry port location planning. By comparing the calculated suitability of areas with present-day locations, we can draw conclusions about earlier location investments and possible new opportunities.

The remainder of the paper is structured as follows: Section 2 introduces the theoretical background through literature review and section 3 explains the methods used in the analysis. The results obtained are presented in section 4 and discussed in section 5. Section 6 presents the conclusions of the study.

2. Literature review

Dry ports drive national economies by playing a pivotal role in the ever-growing realm of international trade. Serving as intermodal transport node (Kurtuluş, 2023; Roso et al., 2015), they relieve congestions at seaports (Awad-Núñez et al., 2014; Rodrigue & Notteboom, 2012), and facilitates export-led strategies (Nguyen & Notteboom, 2016; Nitsche, 2021). The functions and purposes depend on national strategies and port ownership (Wiegmans, Witte, & Roso, 2020). Dry ports play a crucial role for landlocked countries by helping reduce the higher costs associated with the lack of direct sea access.

These countries face specific challenges, including foreign currency service charges, reliance on neighbouring countries for well-functioning infrastructure networks and lack of autonomy in logistics decisions. Therefore, exploring the opportunities offered by dry ports becomes even more essential in this setting. However, studies focusing on landlocked countries is scarce with exceptions including works of Regmi and Hanaoka (2013), Abdoulkarim, Fatouma, and Kalgora (2019) and Jeevan et al. (2022). Conversely, dry ports in developing economies are in the early stages of development. Their establishment is largely driven by inside-out development approaches (Ng & Cetin, 2012; Nguyen & Notteboom, 2016) and is predominantly managed by public entities (Kine, Gebresenbet, Tavasszy, & Ljungberg, 2023; Nguyen & Notteboom, 2016). The current placement of dry ports in these economies lacks robust methodological approach and is largely driven by political decisions (Ng & Cetin, 2012). Therefore a strategic framework that supports dry port location planning particularly for the context of landlocked developing countries is essential.

The location analysis concept is a centuries-old research matter broadly applied in various fields (ReVelle et al., 2008). Its application in logistic and supply chain research is with a primary objective of understanding and implementing location theories to minimize costs and optimize facility utilization. Recently, location analysis and optimization focusing on dry ports have gained substantial attention (de Almeida Rodrigues, de Miranda, Mota, & Manuele dos Santos, 2021; Miraj, Berawi, Zagloel, Sari, & Saroji, 2021). A highly regarded method in such studies involves modelling using an optimisation approach in order to minimize transportation, environmental, investment and shipping costs Ambrosino & Sciomachen, 2014; Wang, Chen, & Huang, 2018; Bouchery et al., 2021; Kurtuluş, 2023). A study by Tsao and Van Thanh (2019) used a similar approach, but also incorporated social elements of costs. The studies begin by randomly proposing potential dry port locations, primarily aligning with the railway network, and then utilise computational techniques to evaluate and determine the optimal choices among the proposed candidates.

Another commonly used approach in dry port location analysis is multi-criteria decision-making (MCDM) (Abdoulkarim et al., 2019; Augustin, Akossiwa, & Esther, 2019; Awad-Núñez et al., 2014; Božičević et al., 2021; Ng & Cetin, 2012; Nguyen & Notteboom, 2016; Tadic, Krstic, Roso, & Brnjac, 2020). Nguyen and Notteboom (2016) set out a framework based on multi-attribute decision-making, while Notteboom (2011) used analytical hierarchy process (AHP) to select the best dry port location among three alternatives. Criteria used in previous studies range from economic and social factors, such as land price, employment rate and population level, to location factors, such as geology and weather (Augustin et al., 2019; Awad-Núñez et al., 2014). Previous location analysis studies followed three main approaches. First groups that propose dry ports and select the best ones either using mathematical or MCDM models. Second group that evaluate the existing dry ports and rank them based on identified criteria. Finally, few studies engage in strategic planning to propose suitable dry port locations without selecting candidate points first. Chang et al. (2015) used location clustering to identify candidate dry ports, however without using empirical criteria weights. Abbasi and Pishvaee (2018) used the AHP method to weigh criteria and then identify suitable locations. The study provides little interpretation of location suitability with respect to sustainability and plausibility of final results, however. This method has also been deployed successfully in other fields of research (Kropielnicki, 2021; Şener, Şener, Nas, & Karagüzel, 2010). The approach could lead public bodies, who in most developing countries control dry ports, make decision on dry port establishment although not exploited in the existing research. Therefore, this study proposes criteria tailored to the context of landlocked and developing countries and applies a GIS tool to develop a suitability map for dry port location planning.

3. Methodology

3.1. Overall study framework

An MCDM analysis using simple multi-attribute technique (SMART) combined with an application in a Geographic Information System (GIS) was used to map the best areas for dry port locations in Ethiopia. Various criteria for selecting dry port locations within the context of landlocked countries were considered from the literature, and suitability analysis in GIS was carried out to identify the most suitable dry port locations. The method was applied to propose suitable locations for future dry port planning in the case of Ethiopia, with the outcomes compared against the location of existing dry ports. Questionnaires were used as a primary source of data when defining and weighting criteria for determining optimal dry port locations. First, a literature review was conducted to identify criteria applied in previous studies. In a subsequent first-phase questionnaire, logistics experts validated the relevance and sufficiency of these criteria for the context of Ethiopia. A second-phase questionnaire was used to apply weightings to the final criteria after analysis with the SMART method. Secondary data were collected to prepare layer files used as input for the GIS analysis. The final criteria, together with their weightings, were then applied to select optimal dry port locations using site suitability analysis function in ArcGIS. Fig. 1 summarizes the overall framework used for the analysis.

3.2. Establishing criteria

The first stage of any MCDM analysis involves defining the criteria for making selections. In the present study, relevant literature on dry port location analysis was used to identify and summarise essential

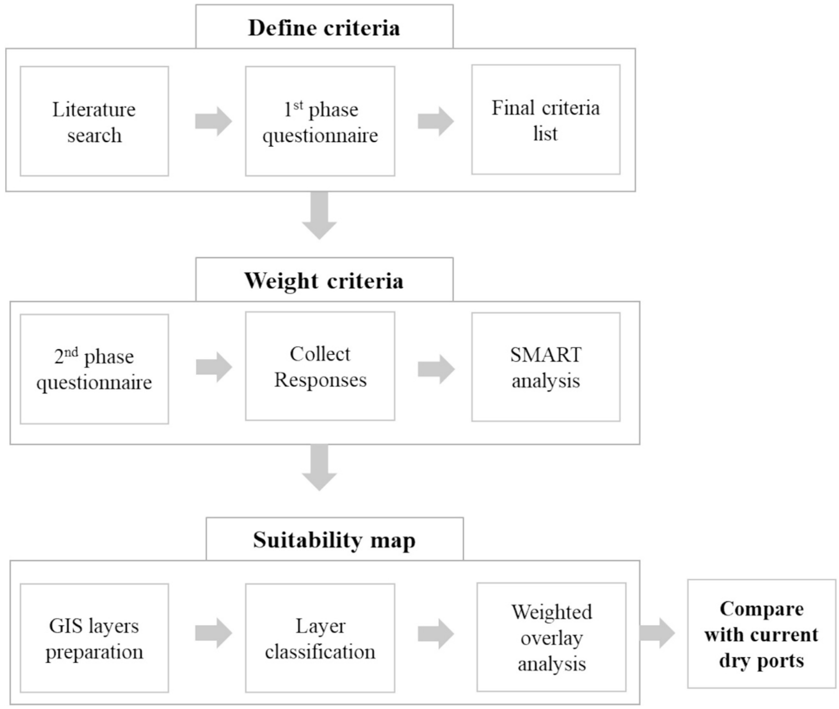

Fig. 1. Research framework deployed in the study.

criteria when selecting optimal dry port locations. All criteria identified from the literature were classified and listed by the authors. The criteria were then presented, via the first-phase questionnaire (see Appendix A), to logistic experts with more than six years of experience in port operations and planning. A total of 13 respondents working in organisations such as Addis Ababa University (AAU), Ethiopian Maritime Authority (EMA), United Nations Conference on Trade and Development (UNCTAD) and Ethiopian Shipping and Logistics Service Enterprise (ESLSE) completed the questionnaire. After receiving the experts' inputs, the final criteria were analysed in three steps: i) Based on the experts' responses and common consensus, the relevance of the criteria for the case of Ethiopia and the need for additional criteria were assessed. ii) Criteria that were recommended to be grouped together were combined. iii) Only the criteria that were available and could be represented as spatial data were retained for the subsequent GIS analysis. The final list of criteria obtained after these analyses were subjected to weighting.

3.3. Criteria weighting

Criteria ranking and weighting in MCDM has been the focus of many studies (Notteboom, 2011; Chang et al., 2015; Nguyen and Notteboom, 2016; Santos and Machado, 2020). Among the MCDM methods available, SMART is the simplest linear additive model (Edwards, 1977; Siregar et al., 2017). Similarly, to other MCDM approaches, SMART uses sets of criteria to compare alternatives and select the best option (Patel, Vashi, & Bhatt, 2017). Decision makers must give each criterion a weighting indicating its importance level compared with the other criteria (Taylor & Love, 2014). The SMART method was employed in the present study due to its simplicity in presenting questions to respondents, making it preferable to compare a larger number of criteria (Kasie, 2013). In addition, it has been identified previously as a suitable method for making decisions on site suitability (Patel et al., 2017).

The SMART method involves the following seven steps (Risawandi & Rahim, 2016; Patel et al., 2017)

1. Define the criteria used.
2. Rank the criteria according to their level of importance.
3. Weight the relative importance each criterion by giving a value of 10 to the least important criterion, and then giving a value from 10 to 100 the next least important criterion relative to the least important one. Continue this process for all criteria.
4. Normalise the relative importance using the formula:

$$NW_j = \frac{W_j}{\sum_{j=1}^{n} W_j} \quad (1)$$

where NW_j is normalised weight of criterion j, W_j is the value of criterion j and $\sum_{j=1}^{n} W_j$ is the total sum of the values for all criteria.

5. Provide a criteria parameter value for each alternative.
6. Calculate utilities for alternatives by multiplying each alternative's values for the criteria by the respective normalised weight of the criteria.
7. Select the best alternative.

In the present study, the application of SMART involved presenting the final list of criteria selected in the previous step to respondents, who were asked to rank them. We included seven respondents in addition to the thirteen experts involved in the first phase. These experts were from Ethiopian Shipping and Logistics Service Enterprise (ESLSE) from port and terminal division and from Ethiopian Maritime Authority (EMA) with more than ten years of experience. The questionnaire used for this case is provided in appendix B.

3.4. Suitability map

The most suitable locations for dry ports, considering the criteria and their weighting, were identified using the ArcGIS software. Weighted overlay analysis was used to merge the spatial information layers for different criteria and calculate suitable dry port areas. Each layer had a different weight, with the higher weight, the greater the impact of a criterion in defining the suitability of an area. *Re*-classified values of the subsections determined the area meeting the criteria. The final suitability value was calculated using the equation:

$$Dry\ port\ suitablity = W_1{*}C_1 + W_2{*}C_2 + W_3{*}C_3 + W_4{*}C_4 + W_5{*}C_5 + W_6{*}C_6 + W_7{*}C_7 \quad (2)$$

where W_j is the weight of each criterion and C_j is the value of each criterion.

The locations of existing dry ports were analysed in relation to the suitability map. To do this, the locations were placed on the suitability map and visually inspected to determine the suitability category into which they fell. In addition, weighted overlay analysis as described above was deployed to study the suitability of land around towns where dry ports are currently installed. First, a polygon around the town was identified and then a buffering distance of 2 km around the town was considered and the suitability of land outside the buffer zone was ranked using four criteria (slope, distance from road, distance from rail, distance from urban area). Similar criteria were considered in proposing new dry port locations around three towns (Nekemte, Jimma and Hawasa) that account for most production of major exported products.

3.5. Application case

Ethiopia was selected as a case study area. Following Eritrea's independence in 1993, Ethiopia became a landlocked country in east Africa, bordered by Eritrea and Djibouti to the north-east, Sudan to the west, Kenya to the south and Somalia to the east and south-east. In 1998, Ethiopia adopted Djibouti seaport as its primary freight gateway and freight traffic hub. Dry ports play a significant role in efficient good transportation and logistics activities in Ethiopia. There are currently eight dry ports, but only one of these has a direct railway connection to Djibouti Seaport (Fig. 2). The Ethiopian Shipping and Logistics Enterprise (ESLE) is in charge of operation and management of the country's dry ports.

4. Results

4.1. Criteria

In a literature review compiled by Mohan and Nasser (2022), location selection criteria are categorised into economic, proximity, site-specific, social and environmental. Criteria such as proximity to transport infrastructure and industrial zones, slope, distance from water bodies and forest zones, distance to population density, land and construction costs have been used in previous dry port location studies (Abbasi & Pishvaee, 2018; Augustin et al., 2019; Nguyen & Notteboom, 2016; Núñez, 2013; Özceylan et al., 2016; Raad, Rajendran, & Salimi, 2022). In the present study, location selection criteria were categorised into economic, topographical, environmental, infrastructural, social and political. Avoiding natural areas and distance from urban areas were among the environmental aspects, while economic factors included closeness to market and production area and potential labour force. Notteboom (2011) also categorised criteria based on the perspectives of stakeholders such as dry port users and service providers. In the broadest classification, the criteria were divided into restrictive and factor criteria (Table 1). Restrictive criteria encompass conditions that constrain construction of a dry port, such as presence of water bodies, and are not prone to weighing. Factor criteria, on the other hand, comprise factors that have an impact on dry port location but without restricting its selection, such as slope, proximity to infrastructure and distance from seaport.

Factors such as local regulations, accessibility to seaports and legislative criteria are specific to geographical location and are not generally applicable in dry port location selection (Mohan & Naseer, 2022; Roso et al., 2015; Tadic et al., 2020). Moreover, no particular criteria specifically applicable to landlocked countries have been identified (Regmi & Hanaoka, 2013; Abdoulkarim et al., 2019). Different researchers have applied MCDM approaches such as analytical hierarchical problem (AHP), analytical network process (ANP), the Delphi method and the

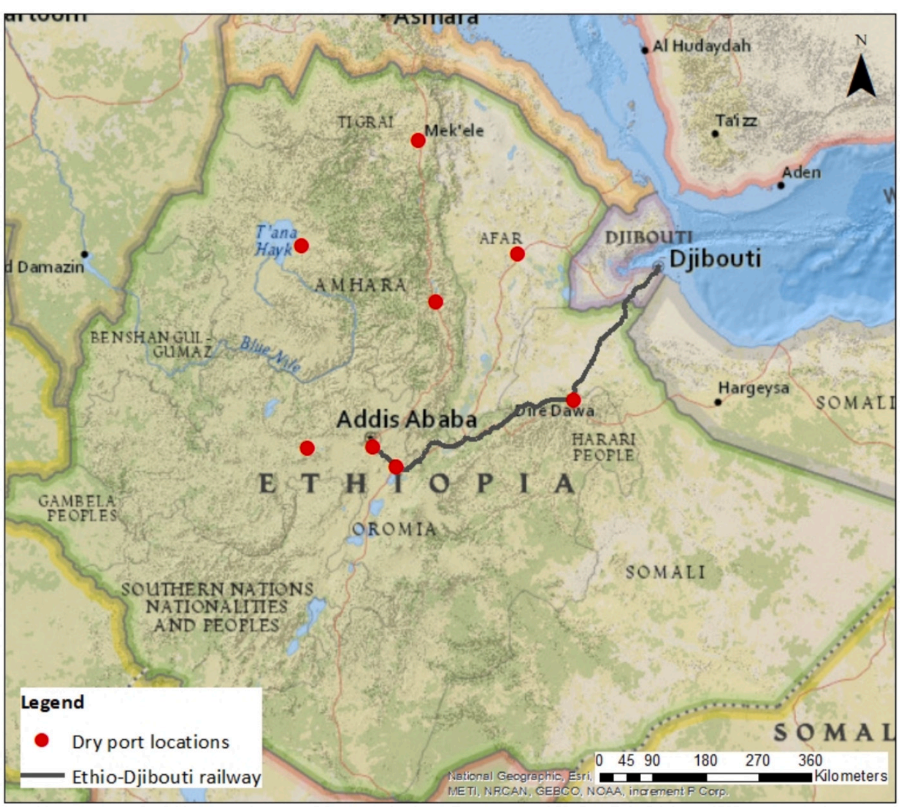

Fig. 2. Map of the study area (source: Kine et al., 2023).

Table 1
Summary of criteria used for determining optimal dry port locations.

Criteria	Sub-criteria	Sources
Restrictive criteria		
Non-building zones		Abbasi & Pishvaee, 2018; Augustin et al., 2019
Presence of water bodies		Abbasi & Pishvaee, 2018; Augustin et al., 2019
Permanent areas with political instability		Notteboom, 2011; Augustin et al., 2019; Raad et al., 2022
Conserved areas		Abbasi & Pishvaee, 2018; Augustin et al., 2019
Availability of electricity		Notteboom, 2011; Chang et al., 2015; Mohan & Naseer, 2022
Factor criteria		
Topographic criteria	Slope	Abbasi & Pishvaee, 2018; Santos & Machado, 2020; Mohan & Naseer, 2022; Raad et al., 2022
	Vegetation	Chang et al., 2015; Augustin et al., 2019; Santos & Machado, 2020; Tadic et al., 2020
Infrastructural criteria	Road hierarchy network	Chang et al., 2015; Abbasi & Pishvaee, 2018; Santos & Machado, 2020; Tadic et al., 2020
	Distance from road network	Abbasi & Pishvaee, 2018; Mohan & Naseer, 2022
	Distance from railway	Abbasi & Pishvaee, 2018; Mohan & Naseer, 2022
	Accessibility to transport infrastructure	Ka, 2011; Roso et al., 2015; Nguyen & Notteboom, 2016; Mohan & Naseer, 2022; Raad et al., 2022
	ICT infrastructure	Mohan & Naseer, 2022; Raad et al., 2022
	Intermodal connectivity	Notteboom, 2011; Tadic et al., 2020
Social and environmental criteria	Distance from urban areas	Notteboom, 2011; Tadic et al., 2020; Mohan & Naseer, 2022; Raad et al., 2022
	Opportunity for expansion	Notteboom, 2011; Augustin et al., 2019; Mohan & Naseer, 2022
	Population density	Notteboom, 2011; Santos & Machado, 2020; Mohan & Naseer, 2022
	Noise and air pollution	Tadic et al., 2020; Mohan & Naseer, 2022
Economic criteria	Closeness to production base	Ka, 2011; Roso et al., 2015; Nguyen & Notteboom, 2016; Mohan & Naseer, 2022
	Closeness to potential marketing area	Roso et al., 2015; Mohan & Naseer, 2022
	Closeness to other logistics platform	Ka, 2011; Nguyen & Notteboom, 2016; Mohan & Naseer, 2022
	Distance from seaport	Abbasi & Pishvaee, 2018; Santos & Machado, 2020; Tadic et al., 2020; Mohan & Naseer, 2022
	Cost of land	Ka, 2011; Nguyen & Notteboom, 2016; Raad et al., 2022; Notteboom, 2011; Mohan & Naseer, 2022
	Potential labour force	Nguyen & Notteboom, 2016; Notteboom, 2011; Mohan & Naseer, 2022; Raad et al., 2022

Best-Worst Method to assess weighted criteria and have identified marked differences. For example, Tadic et al. (2020) identified the potential volume of flow attracted to dry ports as the most important factor of 20 considered in their study. In an analysis focused on peninsular regions, Mohan and Nasser (2022) found that proximity to transport infrastructure such as roads, railways and waterways had the highest importance, while social aspects such as employment opportunities were ranked lowest.

Experts agreed that all the criteria except closeness to other logistics platforms were relevant to the case of Ethiopia. The experience was that logistics platforms in Ethiopia are only nascent and that such offices would locate themselves following the dry port locations. Additionally, it was suggested that the road hierarchy and distance from road could be grouped together by considering high hierarchical roads. For this reason, the study included the federal roads classes in the analysis. Accessibility to transport infrastructure is looked together with distance from road and railway criteria as well. Similarly, cost of land was combined with land use criteria after the first phase questionnaire. The two main means of transport in Ethiopia are road and railway, and the criterion intermodal connectivity is considered with the distance to road and railway criteria. Closeness to areas of economic activity and land use criteria were deemed important to include, in two ways. On the one hand, dry ports would need to be in regions of significant economic activity to have sufficient demand. On the other hand, being too close to heavily urbanized areas could be harmful due to congestion. The primer was reflected in a criterion of location within larger regions of the country designated as being of economic importance. The latter was reflected in a criterion of location at a distance from urban centres. Criteria such as vegetation, conserved area, non-building zones, noise and air pollution could not be obtained and hence were not included in the next analysis. In sum, this study considered criteria that could be presented spatially including slope, distance from road, distance from railway, distance from urban area, closeness to production and marketing area, and distance from seaport. A map of water bodies was used as a restrictive criterion in this study.

4.2. *Weighting of criteria*

The calculated weighting from eq. 2 indicated that distance from road and distance from railway were the most important dry port location selection criteria (weight 0.2 and 0.18, respectively). The next most important factor was closeness to production base, with a decrease in weight to 0.15. Closeness to production base, land slope, closeness to marketing area and distance from urban area had lower weighting (0.14–0.11). Distance from seaport was the least important criterion, with weight of 0.09 (Table 4). The sub-classifications in Table 4 show the categorisation of land for each criterion considered. The values assigned to each criterion are also indicated, with higher values given to the most suitable classes.

4.3. *Scoring of locations*

Spatial data were collected for all criteria from corresponding institutions. A description of the results for each criterion is presented below and the scoring approach for each criterion is discussed. Finally we present the scores for each criterion in maps.

4.3.1. *Road network*

The road networks in the region are classified into six design standards (DS1-DS6) based on the capacity and quality of the road. Road quality is one of the recommended criteria in dry port location analysis (Núñez, 2013). To account for this, we used roads from DS1 to DS3 (which represent federal roads), using data obtained from Ethiopia Road Authority (ERA). Distance from a DSI-DS3 road was then calculated and divided into five groups, where the smaller the distance the more suitable the area (which was given a higher value). Finally, the layer was prepared for further analysis as indicated in Fig. 3a.

4.3.2. *Railway network*

To enhance freight transport in Ethiopia, there have been recent developments in railway transport. The Ethio-Djibouti railway is currently the main service provider in the railway sector, but other railway routes are planned. In this study, both the existing and planned routes were taken into consideration, using data acquired from Ethiopian Railway Corporation (ERC). Similarly to the distance from road

Table 4
Criteria weightings used in identifying the optimal locations of dry ports in Ethiopia.

Criterion	Weight	Sub-classification	Value
Distance from road	0.20	0–5 km	5
		6–10 km	4
		11–20 km	3
		21–30 km	2
		>30 km	1
		0–5 km	5
		6–10 km	4
		11–15 km	3
		16–20 km	2
Distance from railway	0.18	>20 km	1
		Region 1p	5
		Region 2p	4
		Region 3p	3
		Region 4p	2
Closeness to production	0.15	Region 5p	1
		0–8 %	5
		9–15 %	4
		16–25 %	3
		26–45 %	2
Slope	0.14	> 45 %	1
		Region 1 m	5
		Region 2 m	4
		Region 3 m	3
		Region 4 m	2
Closeness to potential marketing area	0.13	Region 5 m	1
		Rural	3
		Sub-urban	2
Distance from urban areas	0.11	Urban	1
		150–175 km	5
		176–200 km	4
Distance from seaport	0.09	201–250 km	3
		251–300 km	2
		>300 km	1

criterion, a distance from railway network criterion was developed. We assumed road drayage would be the main option for connecting to rail, where short distances are crucial for an efficient turnaround process. The layer indicated in Fig. 3b, representing distance from railway, was then created.

4.3.3. Slope

A digital elevation model (DEM) map of Ethiopia was used to generate gradient map by calculating the change in elevation between adjacent cells in GIS. The resulted map was divided into five classes ranging from escarpment to flat areas. As shown in Fig. 32c, most lands was within the flat area class (<8 % slope).

4.3.4. Production area

Based on data from National Bank of Ethiopia (2023), the main exports from Ethiopia are coffee (44 %), flowers (17 %), chat (*Catha edulis*) (8 %), gold (5 %) and oilseeds (5 %). Dry ports should optimally be placed close to these production bases. The 11 regions in Ethiopia were used to weight lands according to the criteria, where each region was assigned a weight based on the percentage of production it contributed (Table 2). Regions with high percentage share were given higher weight (Fig. 3d).

4.3.5. Land use

As indicated in Fig. 3e, almost 80 % of all land in Ethiopia is rural. Greater distance between proposed dry port locations and urban areas alleviates environmental and traffic flow issues, so rural areas were given the highest weight, followed by sub-urban and then urban areas.

4.3.6. Market area

Data from the Ethiopia Customs Commission indicate that transport, agricultural and industrial goods comprise 30 % of total imported goods by value, while fertilisers comprise 22 % and petroleum 15 %. Similar to the distance from production criterion (Table 3), the 11 regions in Ethiopia were re-classified to highlight the most market-attracting areas based on population data and regions accommodating many warehouses. Areas with high population and containing many warehouses were given the highest weight (Fig. 3d).

4.3.7. Distance from seaport

As a land-locked country, Ethiopia uses Djibouti Seaport for 90–95 % of its import-export trade. Land in Ethiopia was classified into five regions based on distance from Djibouti Seaport (Galafi), as shown in Fig. 3f.

4.4. Suitability map for dry port locations

The next step in the analysis was to map areas ranked based on their suitability for dry port establishment, adding the weighted criteria into one overlay map. The resulting layout is shown in Fig. 4. As indicated, only a small proportion of the region fell within the highly suitable and unsuitable categories, comprising approximately 4 % and 1 % of all land, respectively. The highest proportion of available land (82 %) fell within the marginally and moderately suitable categories. The water area indicated in blue in the figure is the area restricted from placing dry ports. The third highest proportion of land was in the least suitable category, and this land was primarily concentrated in the south-east of the country.

The suitability of existing dry port locations in Ethiopia was evaluated by overlaying these locations on the suitability map depicted in Fig. 4 and examining their placement. As Fig. 5 shows, five of the eight dry ports were found to be situated in highly suitable areas, two in moderately suitable areas and one (Kality dry port) in a marginally suitable area. Therefore, within the distribution shown in the suitability map, most of the existing dry ports were found to be concentrated in the highly suitable category.

The sustainability aspect of the existing dry ports was assessed by checking whether they are located within a city or within an urban buffer zone. For this, a map of nearby cities, each with a buffer zone of 2 km, was prepared and overlain with the suitability map and the location of existing dry port sites. The output was a map showing the sustainability ranking of land around the major cities where dry ports are located (Fig. 6). It revealed that Kality, Kombolcha and Mekele dry ports are located within cities (Fig. 6a, d and e, respectively). Consequently, these dry ports will likely contribute for potential traffic congestion and associated negative environmental impacts. Gelan and Mojo dry ports are located in the most suitable category according to location suitability analysis, but they are also located within the 2 km buffer zone from nearby cities (Fig. 6a, b), and this poses a possible challenge if the cities expand in the future. The remaining three dry ports (Dire Dawa, Semera and Wereta) are located outside the city and buffer zones (Fig. 6c, f and g, respectively), in moderately and highly suitable areas (Fig. 5).

Three towns (Hawassa, Jimma and Nekemte) with high potential for production of export goods were selected to assess the suitability of future dry port locations. As Fig. 7c shows, suitable land surrounding Hawassa is limited due to presence of water bodies in the vicinity, but there is some highly suitable land for dry ports in the north-west of that city. In the case of Jimma and Nekemte (Fig. 7a and b), most land around both cities is highly suitable as a location for dry ports.

5. Discussion

5.1. Criteria and weighting

Selecting dry port locations involves MCDM-type strategic planning, as it requires consideration of various constraints and variables to ensure sustainable and efficient dry port operation. Various criteria have been considered from different perspectives in the literature. We followed a

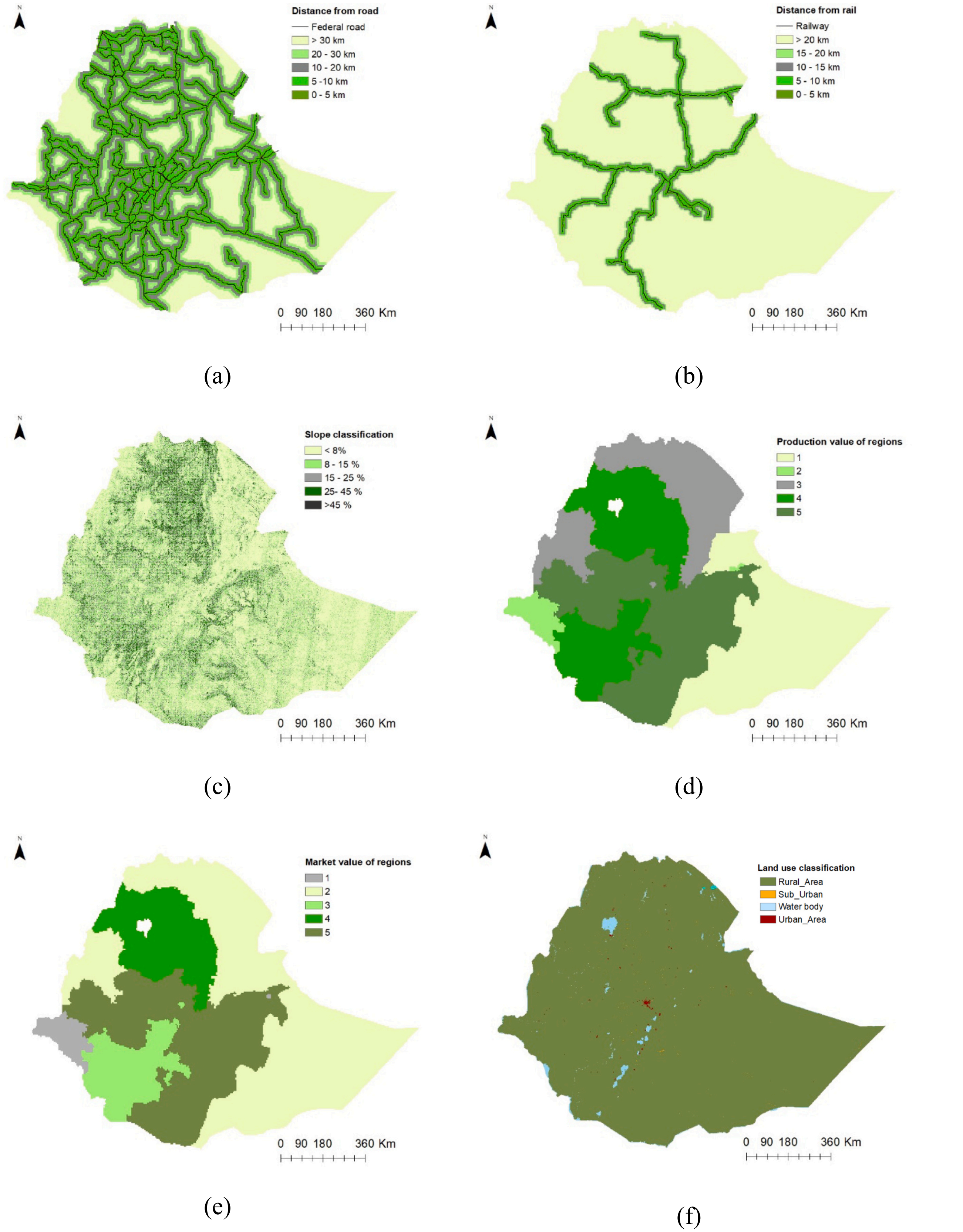

Fig. 3. Individual criteria used to determine suitable dry port locations in Ethiopia, which were classified based on: a) distance from federal roads, b) distance from railway, c) land slope, d) potential production, e) marketing area, f) land use and g) distance from seaport.

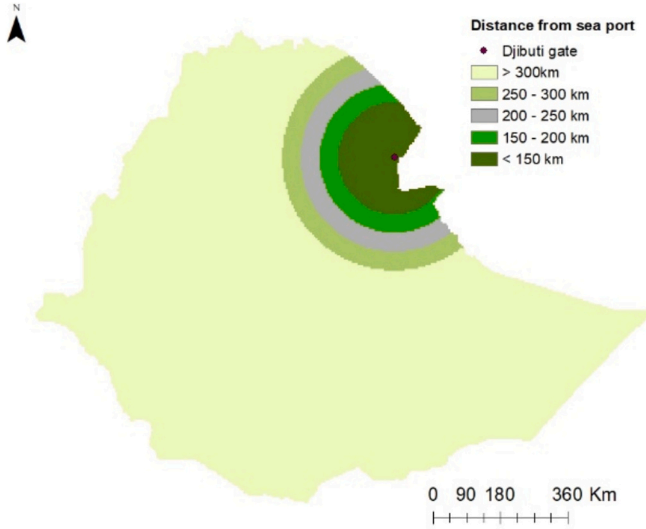

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Fig. 3. (*continued*).

Table 2
Ethiopian regions and their coffee production share.

Region	Coffee production capacity (ha)	Weighting based on coffee production	Warehouse capacity owned by ECX (quintal)	Weighting based on warehouse capacity	Mean weight.	Class value
Addis Ababa	–	–	282,917	0.0856	0.043	3
Oromia	1,128,475	0.65851	828,385	0.2507	0.455	5
Tigray	–	–	328,082	0.0993	0.050	3
Afar	–	–	298,356	0.0903	0.045	3
Amhara	16,009	0.009342	1,066,830	0.3229	0.166	4
Benshangul-Gumz	4655	0.002716	383,959	0.1162	0.059	3
Dire Dawa			54,697	0.0166	0.008	2
Gambela	11,480	0.006699	–	–	0.003	2
Hareri	–	–	–	–	0.000	1
Somalia	–	–	–	–	0.000	1
SNNP[1]	553,066.5	0.32273	604,040	0.0183	0.171	4
Total	1,713,685.5		3,303,630		1.000	

Sources: Ethiopian Coffee and Tea Authority; Ethiopian Ministry Transport and Logistics.
[1] South Nation Nationality People.

Table 3
Ethiopian regions, their population and their share of market activities.

Region	Weight based on population		Weight based on warehouse capacity		Average weight	*Re*-class value
	2022 projected population	Weight 1	Warehouse capacity in quintal	Weight 2		
Addis Ababa	3,860,000	0.0367	1,707,927	0.1934	0,1150	3
Oromia	40,061,000	0.3809	4,207,046	0.4764	0,4286	5
Tigray	5,739,000	0.0546	232,606	0.0263	0,0405	2
Amhara	22,877,000	0.2175	1,953,508	0.2212	0.2193	4
Afar	2,091,000	0.0199	594	0.0001	0.0100	2
Benshangul-Gumz	1,218,000	0.0116	594	0.0001	0.0058	2
Dire Dawa	535,000	0.0051	465,387	0.0527	0.0289	2
Gambela	508,000	0.0048	594	0.0001	0.0024	1
Harari	276,000	0.0026	594	0.0001	0.0013	1
Somali	6,506,000	0.0619	990	0.0001	0.0310	2
SNNP	21,493,000	0.2044	261,992	0.0297	0.1170	3
Total	73,750,748		8,831,833			

Source Ethiopia: Regions, Major Cities & Towns - Population Statistics, Maps, Charts, Weather and Web Information (citypopulation.de).

simple multi-attribute rating technique for weight analysis in this study and found that distance from road and distance from railway were the two highest-weighted criteria for optimal dry port location, with values of 0.2 and 0.18, respectively. This aligns with findings in previous studies (Abbasi & Pishvaee, 2018; Raad et al., 2022). It indicates that the flexibility of roads is preferred over the environmental benefits of

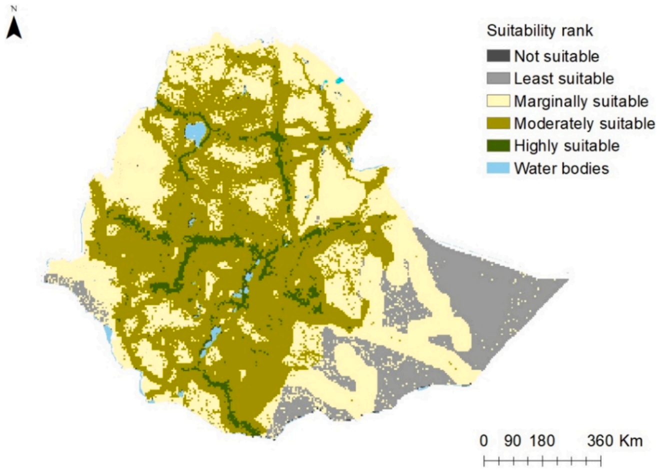

Fig. 4. Suitability map of dry port locations in Ethiopia.

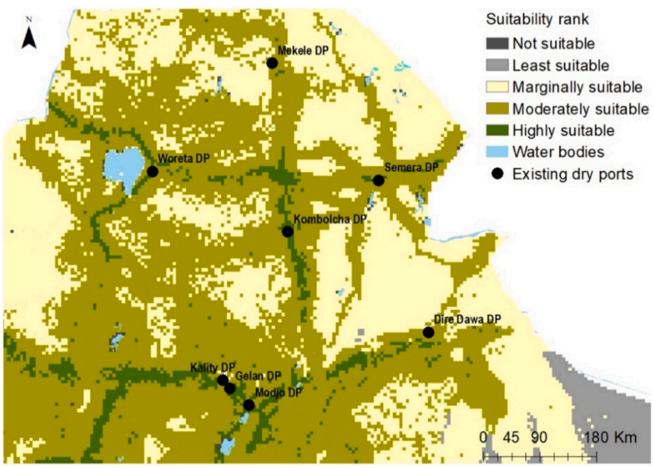

Fig. 5. Location of existing dry ports in Ethiopia relative to the categories in the suitability map.

railways in the study region. Similarly, closeness to production received a higher weight (0.15) than closeness to market (0.13), despite the much higher proportion of exports than imports in Ethiopia. This reflects the country's current drive to boost exports. In contrast, respondents gave the lowest weight to distance from seaport (0.09). A possible reason is that in landlocked countries such as Ethiopia, the primary purpose of establishing dry ports is to save foreign currency expenses incurred at seaports, so fast removal of goods from seaports is more essential than subsequent overland transport distance.

5.2. Suitability map of dry port locations

The suitability map addresses the multi-criteria nature of the problem for location decisions. Subsequent micro-level analysis can simplify and increase the accuracy of location analysis, ensuring that investments in dry port establishment are profitable while meeting their purposes. The overall proportion of highly suitable dry port locations in Ethiopia was found to be low, primarily due to lack of road and railway infrastructure, which were identified as the most important factors in selecting optimal sites. However, based on the case study findings, many highly suitable areas, particularly in western and southern parts of Ethiopia, have not yet been fully exploited. Much land in the south-eastern part appears to be predominantly categorised as least suitable and marginally suitable for dry port location, due to lack of road and railway infrastructure in the area coupled with low production and market value. Delaying dry port construction in that region to coincide with other developments, such as infrastructural improvements, could be considered. The largest proportion of available land in Ethiopia is in the moderately suitable category, indicating further potential to accommodate more dry ports. To address any new needs for dry ports, additional studies on future flows will be needed.

5.3. On existing and proposed dry port locations

The salient finding that existing dry port locations align well with highly suitable areas is an encouraging sign that the tool is suitable for determining dry port locations fitting to national logistics requirements. The placement of Kality dry port in a marginally suitable area is a notable exception, as it contravenes the distance from urban area and export value criteria (Fig. 4). The classification of Mekele and Dire Dawa dry ports into the moderately suitable category is attributable to two main factors: low production for export in the respective area and the presence of rather steep escarpments at both sites, which were ranked as the third and fourth most important criteria for site selection, respectively (Table 4). Gelan and Mojo dry ports lie within the most suitable area identified in location analysis but are located within the 2 km buffer zone from nearby cities (Fig. 5a, b), which poses a potential challenge if these cities expand. In fact, there is a high probability of urban sprawl around these cities in the near future because of their high urbanisation rate and their proximity to the capital city, Addis Ababa, which means that the Gelan and Mojo dry ports will contribute to environmental externalities. Taking into account Ethiopian's export-promoting policies, this study examined the suitability of land surrounding high-production areas. A similar approach can be applied to identify candidate dry port locations based on policy guidelines tailored to the context in other similar countries.

6. Conclusions

Identifying the optimum location of dry port facilities is a crucial element in future planning and requires consideration of restrictive and factor criteria. Restrictive criteria are not subjected to weighting, while factor criteria are. Among the factor criteria analysed in this study, using the SMART method, distance from road was found to be the most important criterion, followed by distance from railway, while distance from seaport was the least important factor. Distance from production areas and marketing areas ranked as the 3rd and 5th most important criteria, respectively, highlighting the significance of economic activities in dry port location planning. ArcGIS was used to map the most suitable dry port locations, using overlay analysis. The approach supports the identification of preliminary areas for dry port sites.

Application of our method for Ethiopia indicated that most available land is only moderately and marginally suitable for dry port location, due to underdeveloped transport infrastructure coverage. For future dry port planning, infrastructure such as roads and railways should be developed concurrently. These findings can be valuable for future dry port planning in Ethiopia. There is a need for further complementary analyses considering flow and network parameters.

Most existing dry port locations fell within the highly suitable area identified in this study, confirming the fitness of the approach. Although situated in highly or moderately suitable sites, the Kombolcha and Mekele dry ports are located near cities, raising concerns about their future environmental impacts. Planning future dry port construction in areas proposed in this study will facilitate export activities. We note that the analysis could be extended to include freight flows and activity levels of existing terminals. This extension could help assess the suitability of specific locations for investments. Finally, we found that the inventory of spatial data in Ethiopia has limitations, especially for production, manufacturing and market areas, leading to challenges in identifying suitable locations and inhibiting dry port planning that facilitates good flows. Future work could consider ways to reduce or

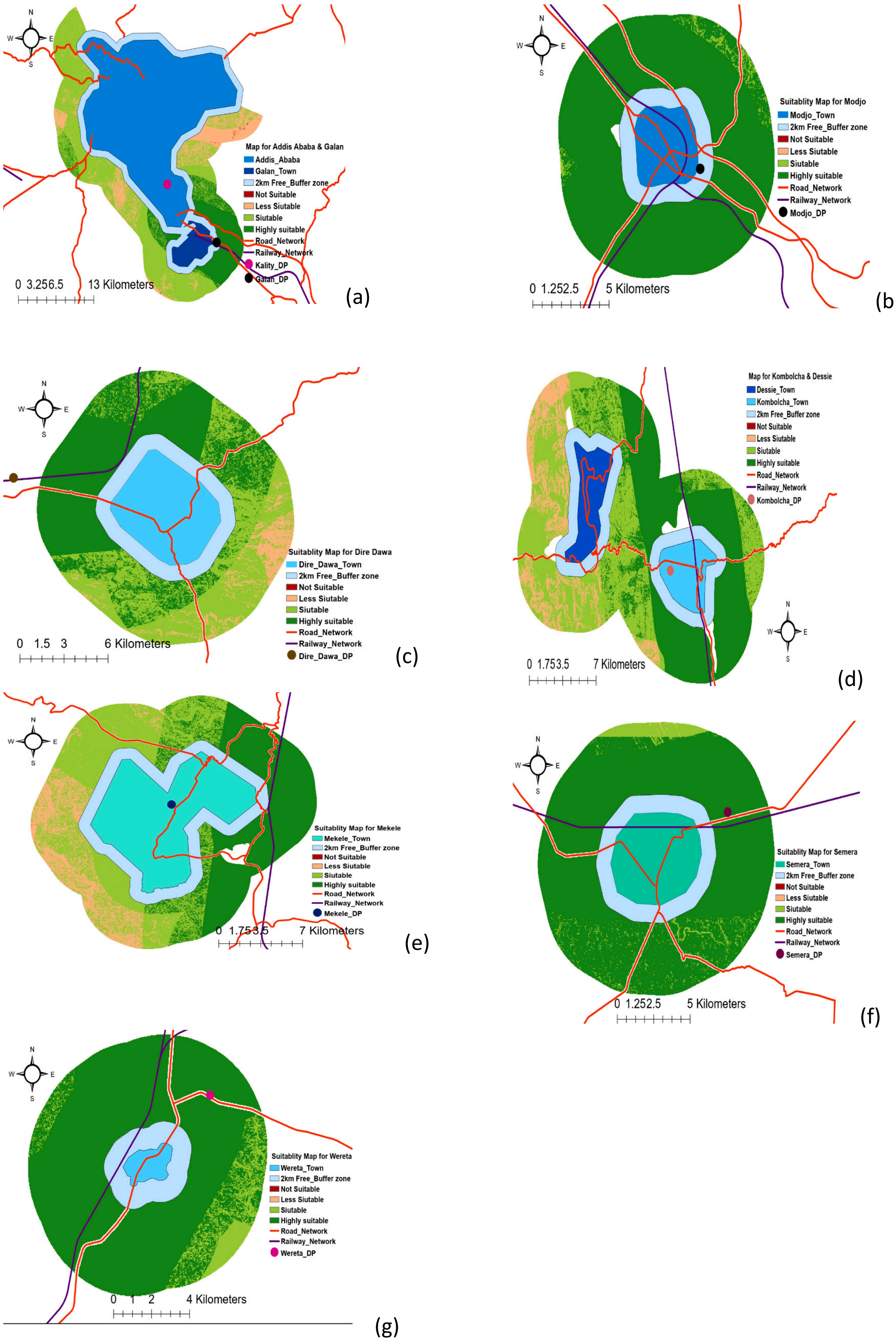

Fig. 6. Suitability in terms of sustainability of land around existing dry ports (DP) in Ethiopia: a) Addis Ababa (Gelan DP, Kality DP), b) Mojo DP, c) Dire Dawa DP, d) Kombolcha DP, e) Mekele DP, f) Semera DP and g) Wereta DP.

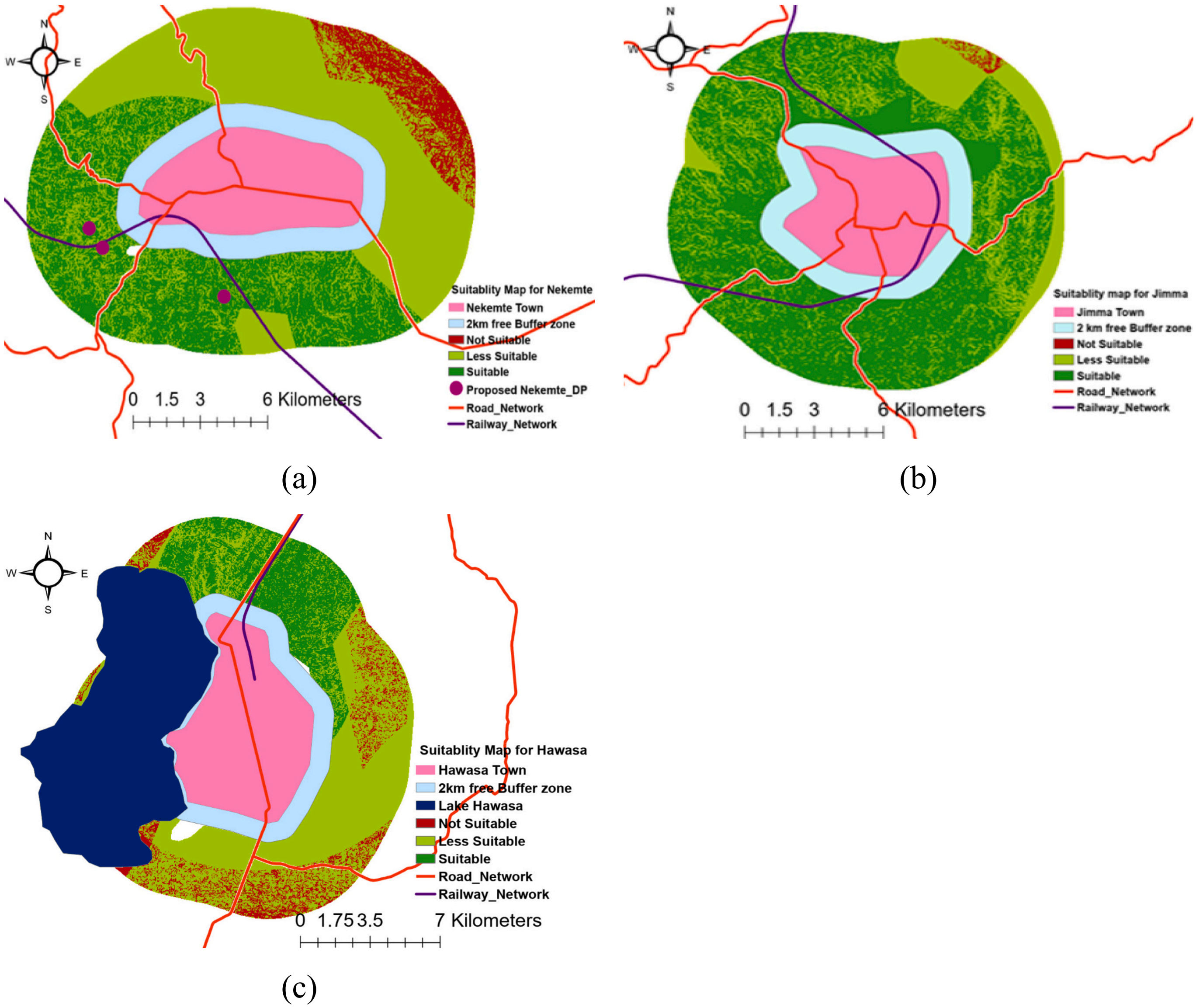

Fig. 7. Potential future dry port locations around three high-production towns in Ethiopia: a) Nekemte b) Jimma and c) Hawasa.

circumvent this lack of data.

Author statment

All the authors have a significant contribution in the design, development, data collection, analysis and writing of this manuscript. We claim that this work is original and has not been published anywhere else. It is not under consideration for publication in any other journal either. We have no conflict of interest to declare and the funding sources are acknowledged in the manuscript. The ethical guidelines have been followed in conducting and presenting the research.

CRediT authorship contribution statement

Helen Zewdie Kine: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Zenebe Shiferaw:** Writing – review & editing, Writing – original draft, Formal analysis, Data curation. **Girma Gebresenbet:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition, Conceptualization. **Lorent Tavasszy:** Writing – review & editing, Supervision. **David Ljungberg:** Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. First phase questionnaire

I. General information
1. What is the name of your organization?
2. Please provide your position in the organization.
3. How many years of experience do you have in your current field of work?

II. The following table shows lists of criteria found from literature that are used to analyse dry port locations. Please identify the ones relevant for locating dry ports in Ethiopia using rating scale of 1 to 5. Please put mark (✓) on the scale that best meets your opinion in the space provided.

Rating scales

Not relevant - 1	Relevant - 4				
Less relevant - 2	Very relevant - 5				
Fairly relevant - 3					
Criteria	1	2	3	4	5
Restrictive criteria	_	_	_	_	_
Non-building zones					
Presence of water bodies					
Areas with political instability					
Permanent conserved areas					
Availability of electricity					
Topographic factors					
Slope					
Vegetation					
Infrastructural factors					
Road Hierarchy Network					
Distance to road network					
Distance to rail					
Accessibility to transport infrastructure					
ICT infrastructure					
Intermodal connectivity					
Social and environmental factors					
Distance from urban areas					
Noise and air pollution					
Opportunity for expansion					
Population Density					
Economic factors					
Closeness to production base					
Potential marketing area					
Closeness to other logistics platform					
Distance from Seaport					
Distance from airport					
Cost of land					
Potential labour force					

III. Are there any additional criteria that should be considered that are not listed above? If yes, please provide them in the table below together with their ranking 1 to 5 using '✓' mark in the provided space.

No.	Additional criteria	1	2	3	4	5
1						
2						
3						
4						
5						
6						

Appendix B. Second phase questionnaire

1. How would you rank the importance of each criterion below in determining the location of dry ports?

Criteria	1st rank	2nd rank	3rd rank	4th rank	5th rank	6th rank	7th rank
Slope							
Distance from road							
Distance from rail							
Distance from urban areas							

(continued on next page)

(*continued*)

Criteria	1st rank	2nd rank	3rd rank	4th rank	5th rank	6th rank	7th rank
Closeness to production base							
Closeness to potential marketing area							
Distance from Seaport							

2. Assign a value of 10 to the least important criteria (the criteria you put in the 7th rank from the question above). Now evaluate the rest of the criteria relative to the least important one on the scale 10–100 by answering the following questions. Ten signifies the least important criterion while hundred is the highest important value.
   2.1. How important, on a scale 10–100, is **Slope** factor relative to the least important factor you provided in selecting dry port location?

   ____

   2.2. How important, on a scale 10–100, is **Distance from road** factor relative to the least important factor you provided in selecting dry port location?

   ____

   2.3. How important, on a scale 10–100, is **Distance from rail** factor relative to the least important factor you provided in selecting dry port location?

   ____

   2.4. How important, on a scale 10–100, is **Distance from urban areas** factor relative to the least important factor you provided in selecting dry port location?

   ____

   2.5. How important, on a scale 10–100, is **Closeness to production base** factor relative to the least important factor you provided in selecting dry port location?

   ____

   2.6. How important, on a scale 10–100, is **Closeness potential marketing area** factor relative to the least important factor you provided in selecting dry port location?

   ____

   2.7. How important, on a scale 10–100, is **Distance from Seaport** factor relative to the least important factor you provided in selecting dry port location?

   ________.

Data availability

Data will be made available on request.

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