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Research Article

Applicability and Cost Implication of Labor-Based Methods for Sustainable Road Maintenance (SRM) in Developing Countries

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Regular maintenance keeps roads in a good working condition for users. Road maintenance can be conducted using labor and machine based methods. In this study, applicability and costs of labor-based, namely employment intensive (EI), labor intensive (LI), and labor-based equipment-supported (LBES) road maintenance methods were investigated with a case study in Tigray region, northern Ethiopia. The objectives of this study were therefore to (a) identify road defects and outline the corresponding labor-based maintenance methods, (b) compare relative costs of the three labor-based road maintenance methods, and (c) explore indicators of sustainable road maintenance (SRM) practices for developing countries. The results of this study showed that the labor-based methods are suitable for maintaining a wide range of road defects such as pavement cracks, bleeding, potholes, and rutting. Results of the cost analysis revealed that the LI and EI were 6% and 36% cheaper than the LBES method for repairing shoulder damage in asphalt roads. Roadside bush clearing using LBES resulted in 40% and 147% cost saving compared to EI and LI methods, respectively. Average share of labor cost compared to combined cost of labor and equipment in EI, LI, and LBES was 97%, 79%, and 37%, respectively. Unit rates of maintenance activities for different labor-based methods were also developed for Tigray region. The developed road maintenance unit rates will be useful for estimating cost of labor-based methods in Tigray and other similar regions in Ethiopia. In this study, 45 suitability indicators under 10 categories and three themes (social, economic, and environmental) were developed to improve future road maintenance practices in developing countries. Finally, it is recommended to use SRM practices to increase sustainability of road infrastructure in developing countries.

1. Introduction

Roads play a great role to economic and social development of a country. If road distresses are completely ignored, the road section can easily deteriorate and fail demanding reconstruction which may result in costs three times more than maintenance costs [1, 2]. Poorly maintained roads hamper traffic mobility and increase road user costs and traffic accidents [3, 4]. Road maintenance is therefore necessary to prolong life span and ensure good quality level of road infrastructure before it is irreversibly damaged [5, 6]. Moreover, regular maintenance of roads sustains good quality and safety of a road, creates job opportunity for local community, and reduces rate of traffic accidents [3, 7].

In terms of their operational frequency, road maintenance activities can be categorized as routine, periodic, and emergency [1, 8]. Routine road maintenance involves small-scale works such as clearing road-side grasses, cleaning of silted ditches and culverts, pothole repair and patching. These maintenance activities are routinely conducted on a road section to protect it from deterioration. Periodic maintenance is carried out at regular and longer time interval for road defects. Periodic maintenance activities include reshaping of road surface, regravelling, maintaining of damaged drainage structures, single surface dressing, thin overlay, and renewal of road markings. Periodic maintenance is relatively costly and demands specialist equipment and skilled manpower. Urgent maintenance is unplanned and immediate response to accident road damages such as landslides, fallen trees, washing of road by flood, and damage of drainage structures.

Road maintenance can be conducted by labor-based and machine-intensive approaches depending on the type, severity, and extent of road distresses. Machine-based road maintenance is often performed in heavy- and large-scale maintenances. Labor-based construction or maintenance is an approach in which major means of production or input is labor force substituting labor for equipment, with the aid of simple hand tools or light equipment [9–11].

According to the Pacific Region Infrastructure Facility [12], labor-based maintenance methods are classified into employment intensive (EI) or length person, labor intensive (LI), and labor-based and light equipment-supported (LBES). EI describes the optimal use of labor taking into account cost and quality of maintenance. EI is more or less similar to the length person approach commonly practised in developing countries. A typical labor content of EI ranges between 40% and 80% [12]. LI describes the maximum use of labor aiming at maximizing employment. It is usually supplemented with simple hand tools. LI is often practiced whenever there is high unemployment due to forcing external factors such as high rate of unemployment, occurrence of drought, and war [13]. The most commonly exercised LI methods are using gang and community labor forces. A typical labor content of LI can reach up to 80% [12]. LBES strives to make use of small-scale equipment to achieve competitive productivity, cost, and quality [12]. For instance, it prioritizes the use of plate compactors and pedestrian vibrating rollers instead of bulldozers and other heavy equipment. This labor-based maintenance method effectively utilizes both labor and equipment to minimize project costs. It usually comprises 15%–40% of labor content [12].

Nowadays, labor-based maintenance methods are favored in developing countries because of cheaper costs and an extra job creation benefit for local community [1, 12]. Labor-based road maintenance methods were successfully applied in developing countries, for example, in Kenya [14], Uganda [5, 15], Ghana [16, 17], Nigeria [18], Nepal [19], and Ethiopia [19] for routine maintenance of gravel roads. In Ghana, labor-based road maintenance created about 2.6 million person days of employment and rehabilitated 1,190 km of gravel roads [16]. In Kenya, around 8,000 km of rural and access roads were routinely maintained by labor-based methods [14].

There are some comparative studies on labor-based and machine-intensive maintenance methods in different countries [17, 20, 21]. These studies showed that labor-based methods are financially cheaper per kilometre and create more employment for local community compared to the machine-intensive methods. A comparative study on cost implication and suitability of the different types of labor-based methods is not well understood and not readily available for implementing road maintenance activities in developing countries. To this effect, it is necessary to outline the applicability of the three labor-based road maintenance methods to different road defects. It is also necessary to highlight the current best practices of road maintenance for promoting sustainable road maintenance (SRM) in developing countries. Therefore, the objectives of this study were to: (a) identify road defects and outline the corresponding labor-based road maintenance methods, (b) compare the relative costs of the three labor-based maintenance methods for different maintenance activities, and (c) explore indicators of SRM practices for developing countries.

2. Materials and Methods

2.1. Formulation of Labor-Based Maintenance Methods and Road Defects Matrix. Maintenance is important to keep the quality of road infrastructure in its initially constructed condition so that it provides convenient service to road users. As a result, it is necessary to formulate a matrix detailing the list of road defects, maintenance activities, and the corresponding labor-based maintenance methods.

The list of road defects and parallel maintenance activities were inventoried from local and global literature sources. The road defects were categorized into different road facilities, namely asphalt, gravel, earth, roadside, drainage structures, and road side furniture. For each maintenance activity, an appropriate labor-based method was selected based on global and local road maintenance experiences and expert knowledge. Correspondingly, necessary materials, tools, or equipment were proposed for the selected labor-based maintenance methods.

2.2. Estimation of Labor-Based Maintenance Costs. A quantity surveyor along with other team members assessed and evaluated the different practices of measurements on materials, costs, and equipment for labor-based maintenance methods. A field survey was conducted in different *woredas* (local administrative units) of Tigray, northern Ethiopia (Figure 1) to collect labor productivity for a given maintenance activity, salary of personnel involved in maintenance of roads and unit rates per kilometre for maintaining a road facility. The collected data was verified and evaluated before it was used for further cost analysis.

Cost estimation was made for different road maintenance activities [22] and labor-based maintenance methods. Unit rates were developed for the different road maintenance activities and the three labour-based maintenance methods. Productivity of crews involved in the labor-based maintenance activity was adapted from [22]. Labor productivity was adjusted for topography considering flat, rolling, and mountainous and escarpment terrains.

Material, labor, and equipment prices were gathered from Tigray regional state Bureau of Construction, Road, and Transport, Office of Construction Regulation, Licensing and Registration. For the EI maintenance method, one person living nearby the road section was considered to carry out the labor-based maintenance activities. The length of a road section assigned to a length person ranged between 1 and 2 km, depending on the topography of the terrain. The working time of a length person was 24 hr per week. One foreman or superintendent was assumed to supervise 15 length person workers. The tools often used by a length person for road maintenance activities were wheelbarrow, shovel, hoe, and hand rammer.

For the LI maintenance method, a crew of 2–20 people were established depending on the scope of the maintenance activities. In this study, a crew of 10 people was assumed to

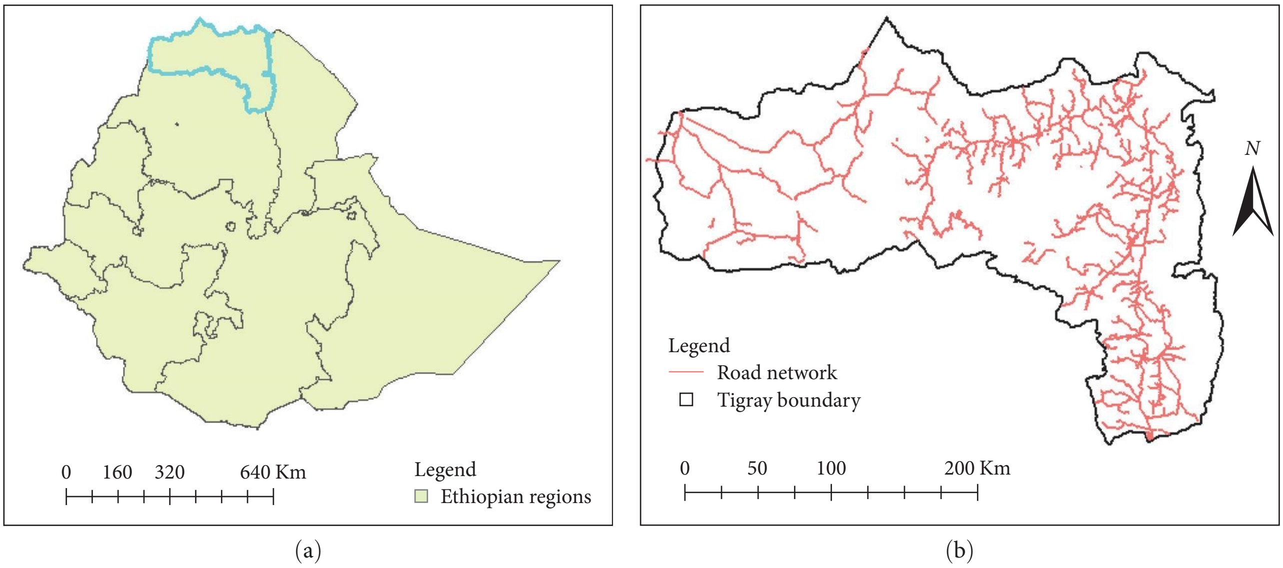


FIGURE 1: Map of study area (a) Ethiopia, (b) road network in Tigray region.

carry out the road maintenance activities. The established crew was composed of local residents, graduates of technical schools, and/or university. The tools often used by the LI crew were wheelbarrow, shovel, hoe, and hand rammer.

For the LBES maintenance method, a crew of 2–20 people were established depending on the scope of the maintenance activities. The size of crew in LBES also depends on the type of equipment used to support the road maintenance activities. The established crew was composed of local residents, graduates of technical schools, and/or university. The leader of the crew should have supervision and management skills. The equipment often used by the LBES maintenance method were wheelbarrow, hoe, shovel, mason hand tools, plate compactor, hand rammer, tractor, water bowser, tipping trailer, grader, and roller. Detail description of the tools and equipment that support labor-based road maintenance can be found in Petts [23].

Road maintenance unit rates were prepared for each maintenance activity considering severity and extent of a road distress. Severity and extent values for a distressed road were adopted from Ethiopian Road Authority (ERA) manual [24]. For the three labor-based maintenance methods, the share of labor and equipment costs were enumerated for each maintenance activity keeping material and indirect costs constant. To illustrate the effect of distress severity and extent, maintenance costs were compared for the three maintenance methods, with two case studies of a 5 km asphalt (Dansha to Humera) and gravel (Mazorya to Shiglil) road segments in Western Tigray. The case study maintenance activities were shoulder repair of a road segment from Dansha to Humera and bush clearing of a road segment from Mazorya to Shiglil.

3. Results and Discussion

3.1. Labor-Based Road Maintenance Practices in Developing Countries. Road maintenance using labor-based methods has been a common practice in many developing countries [5, 14, 16, 18, 25]. The first sub-Saharan African country to introduce labor-based approach in local road contracting industry was Ghana [16]. The program was introduced in 1986 and continued until 1994 by allowing participants to execute labor-based contracts. Awarding the projects was based on engineers fixed rates without tendered bids to protect the labor-based from equipment-based contractors outside the program. In the first 8 years, between 1986 and 1994, the program successfully created about 2.6 million person days of employment and rehabilitated 1,190 km of gravel roads.

Labor-based road maintenance was also successfully implemented in Botswana. In 1979, a pilot project was established to investigate the viability of labor-based road construction and maintenance methods in Botswana [10, 26]. Based on the success of the pilot project, the labor-based program was upscaled throughout in Botswana. As a result, about 816 km of roads were upgraded to different standards till 1986. Moreover, about 7,000 people were employed in the labor-based road improvement and maintenance program. About 50% of the employments in the labor-based rural road programs in Botswana belonged to the rural poor community [27].

There were also successful labor-based routine road maintenance experiences in Nepal. The Nepalese Department of Roads was responsible for performing routine, periodic, and emergency road maintenance activities [28]. Road maintenance expenses (2007–2016) in Nepal represented about 28% of the total road construction expenditure [28]. In that period (2007–2016), about 2,570 and 9,700 km length of roads were maintained using regular and periodic road maintenance activities, respectively.

Peru is one of the most successful country from Latin America to have successfully applied labor-based methods for maintaining rural roads [18]. The rural road program in Peru was responsible for training and contracting microenterprises to carry out routine maintenance for rural road networks. Each enterprise was contracted to maintain a 25 km road length with a payment rate of 750 USD per kilometre per year. The labor-based road maintenance program has created permanent employment for more than 5,000 people in rural areas [18]. With this program, about 7,000 km of nonmotorized access roads were maintained and rehabilitated [29].

The size of road network in Ethiopia has significantly increased in recent years due to the high attention by the government to construction, maintenance, and rehabilitation of roads. The commencement of rural road rehabilitation in 1970 has resulted in construction of about 127,328 km of rural roads till 2010 using labor-based and machine-based methods [18]. Most of urban and rural roads in Ethiopia were maintained using the length person approach. Financial constraints for road maintenance in Ethiopia were relieved due to an establishment of the Ethiopian Road Fund in 1997. The Ethiopian Road Fund finances all routine and periodic maintenances both in urban and rural road networks. Overall, Ethiopia was a good performer in road maintenance [3].

The length person road contract system is commonly used in Ethiopia for maintaining routine maintenance activities in rural roads [30]. The length person maintenance method has been successfully implemented in Tigray region mainly as a routine maintenance activity for preserving the quality of gravel road surface, clearing drainage structures, and protection of a road infrastructure from erosion. The primary activities of the length person maintenance involve spot smoothening and resurfacing of a carriageway with new gravel and refilling of potholes to restore riding quality of the road.

Routine road maintenance activities were performed when there is damage on a length person's road segment. Often, the road maintenance foreman assesses the length person road condition and suggests a maintenance activity for a damaged road segment. The length of road segment assigned to the length person worker depends on the road condition and topography. Nowadays, the length of road segment assigned to a length person worker depends on the terrain of the road segment, and usually ranges between 1 and 2 km. Road maintenance activities in Tigray were financed by the Ethiopian Road Fund.

Although several labor-based road maintenance practices were documented in developing countries, it is still a challenge for labor-based methods to be as competitive as equipment or machine-based methods. Because of the availability of ample labor force, developing countries need to develop strategies and policies that create conducive environment for labor-based road maintenance methods to compete with machine-based methods. Moreover, the road sector in developing countries need to be improved by developing sustainability indicators in road maintenance.

3.2. Applicability of Labor-Based Methods for Maintaining Road Defects. Labor-based road maintenance activities are carried out manually, with the aid of simple hand tools or often supported with light to heavy equipment. The labor-based maintenance methods are used to carry road maintenance activities for various road defects. Road maintenance activities are often carried out after road condition assessment of the type, severity, and extent of road defects. Figure 2, for example, shows types of road defects in Maichew to Adishihu road segment in Tigray region.

The first 15 km of the Maichew to Adishihu road segment was observed to have several road defects such as alligator cracking, potholes, raveling, and rutting. Some of the curved sections were heavily deformed due to combined effects of traffic load and water erosion, in which scour and silt deposition can be easily seen at the curved sections (Figure 2). Based on the ERA pavement condition index (PCI) rating adapted from US Army Corps of Engineers [31], the road condition of the Maichew to Adishihu segment ranged from "Poor" to "Very good" (Figure 3). The average PCI rating for the Maichew to Adishihu road segment was "Fair". The ERA PCI rating scale is very poor for $PCI < 35$, poor for $35 < PCI < 50$, fair for $50 < PCI < 70$, good for $70 < PCI < 85$, and very good for $PCI > 85$.

The descriptions of road defects, maintenance activities, labor-based maintenance methods, and required materials, tools and equipment to conduct the maintenance tasks are summarized in Table 1. A road facility was classified into asphalt pavement, gravel road, earth road, roadside, drainage, structure, and roadside furniture. Most of the maintenance tasks can preferably be carried out using LI and EI methods (Table 1). Some maintenance tasks such as surface patching, light grading, clearing, and removal of obstructions can also be performed using the LBES maintenance method.

3.3. Cost Comparison of Labor-Based Maintenance Methods

3.3.1. Unit Rates of Labor-Based Maintenance Activities. Unit rates of labor-based maintenance methods, illustrated in Table 2, were formulated based on results of cost analyses from two case study road segments in Tigray region. The case study road segments were a 5 km Dansha to Humera asphalt road and 5 km Mazorya to Shiglil gravel road. The maintenance activities for the two case studies were shoulder repair for Dansha to Humera asphalt road and bush clearing for Mazorya to Shiglil road.

Based on the unit cost analysis result (Table 2), activities such as spot repair of gravel roads with selected material, culvert clearing, ditch cleaning, repair of erosion damage with selected soil, and bush clearing were more economical to be maintained by an EI. If more jobs are desired, culvert cleaning, ditch cleaning, and repair of erosion damage with selected material can be performed using the LI method, still a cheaper option than the LBES method.

The unit rate of maintenance costs for repair of erosion damage with rockfill, repair of mortared and dry masonries, and bush clearing were quite similar for LI and LBES methods. Other maintenance activities (Table 2) such as asphalt patching, crack sealing, pothole reinstatement, pothole repair, shoulder rehabilitation, and concrete construction were technically difficult with EI, LI, and can only be carried out using the LBES maintenance method.

The developed unit rates (Table 2) can be used for estimation of road maintenance costs in Tigray and other regions in Ethiopia which have similar labor productivity and topography. The challenge in preparation of unit rates

Figure 2: Road condition for Maichew to Adishihu asphalt road segment with (a) potholes and cracking, (b) pavement deformation at a curve, (c) rutting and raveling, and (d) patches with pothole defects.

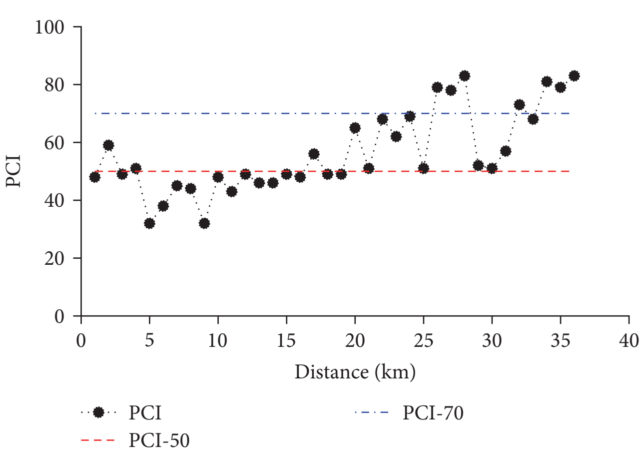


Figure 3: Variation of road condition along the Maichew to Adishihu segment.

of maintenance activities using the labor-based maintenance methods is the absence of labor productivity standards. For proper estimation of labor-based methods, at least country-specific labor productivity standards need to be established taking into account the main factors that affect labor productivity [13, 33, 34]. To accurately estimate labor productivity, it is necessary to use historical productivity records instead of solely relying on literature or own experience [35].

3.3.2. Share of Labor and Equipment Costs in Labor-based Maintenance Methods. The share of labor and equipment costs in the three labor-based maintenance methods can vary from one maintenance activity to the other. In this study, average share of labor cost compared to total costs of labor and equipment keeping material and indirect costs constant in the EI, LI, and LBES maintenance methods was 97%, 79%, 37%, respectively (Figure 4). Similarly, average share of equipment cost in the EI, LI, and LBES maintenance methods was 3%, 21%, and 63%, respectively.

The average share of labor cost in EI and LI of this study (97% for EI; 79% for LI) are considerably higher than the 65% share of labor cost in a labor-based method of road construction reported by Dunffa et al. [20]. The 37% share of labor cost in the LBES maintenance method of this study is also smaller than the 65% reported in Dunffa et al. [20]. The difference in share of labor cost in labor-based maintenance methods

Table 1: Description of road defect types, maintenance activities, and labor-based maintenance methods [12, 23, 30, 32].

Type of facility	Type of defect	Maintenance activity	Maintenance method	Materials/tools/equipment
Asphalt pavement	Bleeding	Sanding	LI	Shovel, truck/trailer, and broom
	Crack	Local sealing	LI	Broom, cutback/bitumen emulsion, spray lance, chalk, and aggregate/sand
	Crack	Crack sealing	LI	Broom, cutback/bitumen emulsion, spray lance, chalk, aggregate/sand, and wheelbarrow
	Alligator cracking, pothole, failed patches	Surface patching	LI, LBES	Aggregate, bitumen, and rammer/plat compactor/roller
	Alligator cracking, shoving, pothole, and rutting	Base patching	LI, LBES	Aggregate, bitumen, cutter, shovel, and hoe rammer/plat compactor/roller
Gravel road	Corrugation, shallow ruts and flat camber (depth < 3 cm)	Light grading	EI, LI, LBES	Pickaxe, hoe, rakes, wheelbarrow, hand hammer/roller, pegs, camber board, sprit level, tape, sprinkler, shovel, and string lines
	Pothole	Spot repairing	EI, LI	Selected gravel/crushed stone, water, roller/hand rammer, sprinkler, shovel, hoe, racks, and wheelbarrow
Earth road	Potholed, rutted or uneven surface	Reshape and compact earth road camber	EI, LI	Roadside material, selected gravel, water, roller/hand rammer, sprinkler, shovel, hoe, racks, wheelbarrow, pegs, camber board, sprit level, and string lines
Roadside	Grass and weeds growing	Grass and cutting	EI, LI	Sickles, scythes, slashers, bush knives, etc.
	Bushes and trees growing	Bush and trees clearing	EI, LI	Saw, axes, ladders, ropes, etc.
	Shoulder erosion, miss-shaped and doesn't drain	Shoulder rehabilitation	EI, LI	Pickaxe, hoe, rakes, wheelbarrow, hand hammer/roller, pegs, camber board, sprit level, tape, sprinkler, shovel, and string lines
	Side slope erosion	Grass seeding or sodding	EI, LI	Grass seed, top soil, water, fertilizer, racks, and sprinkler
	Fallen rocks and earth materials	Clearing and removal of obstructions	EI, LI, LBES	Shovel, hoe, silage hammer, chisel, wheelbarrow, and truck/tractor-trailer
Drainage	Culvert siltation and obstruction	Culvert clearing, cleaning, de-silting, unblocking or removal of vegetation/flood or wind born debris	EI, LI	Hoe, shovel, silage hammer, and bolster chisel/spike, axe, bush knives
	Side ditch siltation and obstruction	Ditch clearing	EI, LI	Hoe, shovel, silage hammer, bolster chisel/spike, axe, and bush knives
	Ditch erosion	Erosion repair (selected fill), scour checks, plant grass, rock fill	EI, LI	Stone, selected material, grass seed, water, shovel, hoe, and hammer
	Slope erosion	Stone pitching, reducing slope angle, clearing slip material, wattling, gabions, retaining wall	LI	Stone, grass seed, water, gabion, cement, aggregate shovel, hoe, hammer, formwork, mortar, and rake
	Masonry (dry or mortar) damage	Masonry repair	LI	Stone, mortar, water, hammer, chisel, sprinkler, string line, and plumb bob
	Gabion structure damage	Gabion structure repair	LI	Stone/rock, gabion, and binding wire
	Blocked/silted manhole	Manhole clearing	LI	Hoe, shovel, and rake
Structure and road side furniture	Connectors or fixings damaged, loose or missing	Repair of loose/missing connectors or fixings	LI	Nail, bolt, fixtures, and screws
	Paint work defective or damaged	Paint main/minor parts of structure or furniture	LI	Brush, string line, and paint
	Structure furniture defective or missing	Replacing or repairing of parapets, marker posts, safety barriers, and signs	LI	Relevant road furniture
	Apron damaged	Apron repairing	LI	Gabion, stone, and concrete
	Minor masonry or concrete or joints defective	Pointing or repair of masonry or concrete	LI	Mortar, concrete

EI, employment intensive; LI, labor intensive; LBES, labor-based equipment supported.

Table 2: Unit rate of maintenance activities for different labor-based methods.

No	Maintenance activity	Scope	Unit	Unit rate (USD per unit) Employment intensive (EI)	Labor intensive (LI)	Labor-based equipment supported (LBES)
1	Spot repair gravel road (selected material)	pavement	m^3	9.0	12.8	13.6
2	Spot repair gravel road (crushed aggregate)	pavement	m^3	24.9	27.2	24.1
3	Culvert cleaning	drainage	m^3	6.1	9.9	10.6
4	Manual ditch cleaning	drainage	m	0.4	0.6	0.7
5	Repair of erosion damage with selected fill	drainage	m^3	6.1	7.3	8.3
6	Repair of erosion damage with rock fill	drainage	m^3	na	13.6	13.0
7	Mortared masonry repair	drainage	m^3	na	69.8	69.9
8	Dry masonry repair	drainage	m^3	na	34.9	34.9
9	Gabion structure	drainage	m^3	na	14.5	14.5
10	Bush clearing	roadside	m^2	0.7	1.2	1.2
11	Asphalt patching with seal coat	pavement	m^2	na	na	8.7
12	Asphalt patching cold mix	pavement	m^3	na	na	177.6
13	Asphalt patching with hot mini–mix	pavement	m^3	na	na	266.6
14	Crack sealing individual cracks	pavement	Lm	na	na	0.7
15	Pothole reinstatement with cold mix	pavement	m^3	na	na	67.5
16	Pothole reinstatement with hot mini–mix	pavement	m^3	na	na	76.9
17	Pothole base failure repair	pavement	m^3	na	na	7.6
18	Light blading gravel road	pavement	Km	na	na	12.9
19	Gravel provision with selected material	pavement	m^3	na	na	2.1
20	Gravel provision with crushed aggregate	pavement	m^3	na	na	5.8
21	Machine ditch cleaning	drainage	km	na	na	61.8
22	Shoulder blading	roadside	km	na	na	9.8
23	Shoulder rehabilitation	roadside	m^3	na	na	2.4
24	Concrete construction (Class 1)	structure	m^3	na	na	60.0
25	Concrete construction (Class 2)	structure	m^3	na	na	48.2
26	Steel reinforcement	structure	kg	na	na	0.6
27	Sand seal coat	pavement	m^2	na	na	0.5
28	Gravel resurfacing with selected material	pavement	m^3	na	na	3.2
29	Gravel resurfacing with crushed aggregate	pavement	m^3	na	na	6.6

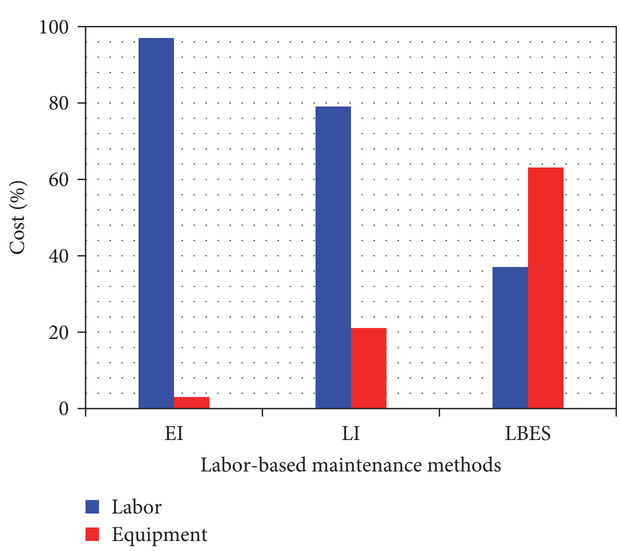
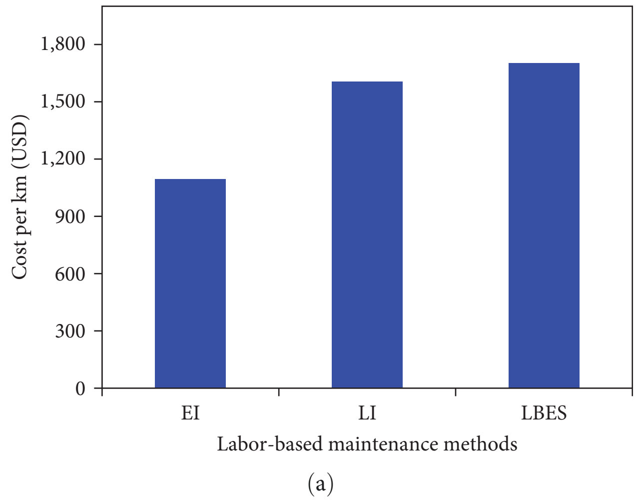


Figure 4: Share of labor and equipment costs in employment intensive (EI), labor intensive (LI), and labor-based equipment supported (LBES) maintenance methods.

between this study and that of Dunffa et al. [20] could probably have resulted from the consideration of the three types of labor maintenance methods into one category with "labour-based" methods in Dunffa et al. [20]. According to [12], similar to this study, labor-based methods are categorized into EI, LI, and LBES methods.

The unit costs (USD/km) of shoulder repair of a road segment from Dansha to Humera using the EI, LI, and LBES methods were 1,097, 1,606, and 1,703, respectively (Figure 5). This result shows that the EI method is 36% cheaper than the LBES method for conducting shoulder repair in asphalt roads. The LI method was however only 6% cheaper than the LBES method for conducting shoulder repair in asphalt roads. The lower cost of EI in shoulder repair of asphalt roads than the LBES method could be due to the higher cost of equipment in the LBES method. The similarity in maintenance costs of shoulder repair for LI and LBES may be attributed to higher number of laborers in the LI than the EI method. As described in Section 2.2, the number of laborers in the LI is 10 while that of EI is usually one person.



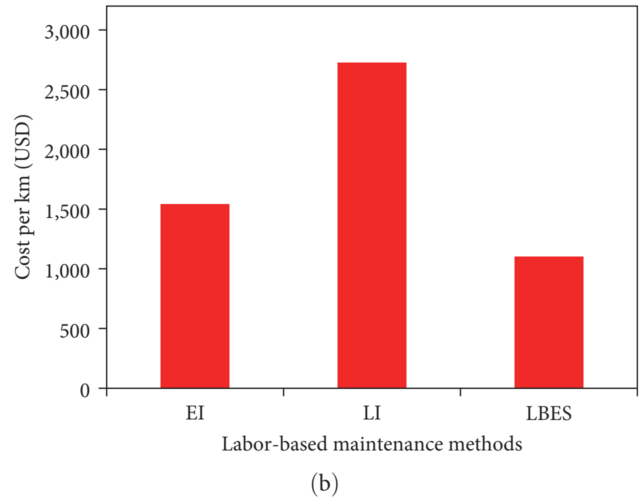


Figure 5: Cost per kilometre for maintaining roads in western Tigray (a) shoulder repair of an asphalt road segment from Dansha to Humera, (b) bush clearing of a gravel road segment from Mazorya to Shiglil. EI, employment intensive, LI, labor intensive, LBES, labor-based equipment supported.

The unit costs (USD/km) of bush clearing of a road segment from Mazorya to Shiglil using the EI, LI, and LBES methods were 1,542, 2,728, and 1,103, respectively. This result shows that the LBES maintenance method is the most economical alternative for clearing roadside bush than the EI and LI methods. The LBES method was 40% and 147% cheaper than EI and LI, respectively. The smaller cost of bush clearing per kilometre of a gravel road using the LBES than the EI and LI methods could be due to better productivity of equipment in the LBES maintenance method.

The lower cost of EI and LI methods compared to LBES for maintaining shoulder of an asphalt road is in agreement with previous comparative studies of labor-based and machine-based methods [17, 20, 21]. The cost per kilometre of labor-based methods was 40% cheaper than machine-based methods in rehabilitation of feeder roads in Ghana [17]. In Nigeria, labor-based construction of a typical rural road was 40% cheaper than a machine-based method [21]. Similarly, Dunffa et al. [20] reported a 47% reduction in construction costs of Universal Rural Road Access Program (URAP) roads in Ethiopia with labor-based than machine-based methods.

3.4. Toward Sustainable Road Maintenance (SRM) Practices in Developing Countries

3.4.1. What Is Sustainable Road Maintenance? By the time roads are open for service, they are subjected to traffic loading and environmental effects that may result in functional and structural deterioration demanding preservation and maintenance [36]. With the ever increasing road networks and limited resources available, timely maintenance of roads is essential to keep good service of roads and minimize operational costs. Road maintenance is therefore necessary to prolong life span and ensure good quality level of road infrastructure before it is irreversibly damaged [5, 6].

Nowadays, there is a strong initiative to develop SRM strategies and policies in developing countries [37–39]. This involves timely maintenance of roads instead of rehabilitation after prolonged damage of the road infrastructure. Donors are also urging governments to decrease road rehabilitation programs and focus on timely routine and periodic road maintenance practices [38].

Sustainability according to UN [40] is meeting the needs of the present without compromising the ability of future generations to meet their own needs. In contrast, Litman [41] described sustainability as integrated human activities that lead to coordinated planning among various stakeholders. Sustainability in the context of road maintenance can be described as prolonging the durability of the road infrastructure with minimum maintenance costs and sustaining the intended uses of roads [42]. Sustainability in road construction is generally described in the form of three pillars or themes: economic, social, and environmental [36, 41, 43, 44]. Each of these three pillars are affected by the goals, demands, characteristics location, materials, and constraints of a given project.

SRM can be achieved by selecting affordable locally available materials, reducing fuel consumption during material transport, avoiding traffic delays, and noise emissions during maintenance [37, 39]. The use of local materials for road maintenance, for example, decreases the overall costs of maintenance because of reduced transport costs of selected materials from distant quarry sites. Besides, it creates employment opportunity to the local community and provides access to social services, thereby making the rural residents resilient to external adversaries [39]. Where applicable, recyclable industrial byproducts can also be used for construction and maintenance of roads [45, 46]. Sustainability of future roads in developing countries can therefore be achieved by implementing SRM practices. Besides, governments in developing countries should have strong initiation and commitment to the development and implementation of SRM practices.

3.4.2. Measuring Sustainability: Exploring Sustainability Indicators. Road maintenance policies affect the sustainability of road infrastructure although their impacts are rarely

Table 3: Sustainability indicators for road maintenance practices.

No	Category	Sustainability indicators	Themes	References
1	Planning	Consistency and coordination with regional and/or national plan Environmental management plan Integration with land use plan Program for road asset monitoring/management Access management plan	Social, economic, and environmental	[44, 45]
2	Employment and training	Impartial hiring practices Fair payment and reasonable workload Reasonable working hours and adequate breaks Quality accommodation for workers Work satisfaction and social acceptance Job stability and security Equal employment opportunities to all members of the society Commitment to anticorruption Delivery of trainings to employs on use of equipment and maintenance methods	Social	[45, 48, 49]
3	Stakeholder participation	Stakeholders consultation in need assessment Stakeholder participation in planning and implementation Stakeholder participation in facility upkeep Timely information dissemination to stakeholders	Social, economic, and environmental	[42, 44, 45, 48, 49]
4	Culture and heritage	Preservation of local culture and heritage Preservation of local features and important sites	Social	[48, 49]
5	Health and safety	Healthy and safe living conditions for nearby residents Elimination of nuisances (e.g., dust, vibration, noise, and odors) Health checkups for employs Safety measures for construction workers Users time saving	Social and economic	[49, 50]
6	Environmental impact	Prevention of air, water, and noise pollution Green and sustainable maintenance Avoid or minimize mobility disruptions during maintenance Preserve habitat and ecology Construction waste management plan Minimization of waste production Efficient energy usage	Social and environmental	[44, 49, 50]
7	Equity	Equal rights and opportunities to all members of the society Equal access to key facilities	Social	[49]
8	Natural resources	Competent material selection and usage Reduced water use and preserving water quality Reuse or recycling of materials Use of renewable and local materials	Environmental and economic	[38, 40, 45, 49]
9	Financial competency	Sustainable financial investment Funding plan for administration and maintenance Cost-effective design alternative and maintenance methods Funding plan for research and development	Economic and social	[49]
10	Innovation, quality, and productivity	Implementation of quality management plan Innovative and rapid maintenance technique Performance based maintenance contracting	Social, economic, and environmental	[44]

quantified [47]. A set of indicators are useful for identifying trends, setting targets, and measuring progress of a road maintenance program. These indicators, determined by considering specific local parameters such as climate, public priorities, and resource availability together with the global basic parameters are often used to evaluate sustainability of a scheme [41, 43]. According to Litman [41] indicators are described in terms of targets and thresholds, as means that everyone uses to assess performances toward predefined goals and objectives.

Some road maintenance sustainability indicators were proposed by de Bortoli et al. [47] to estimate the impacts of road maintenance programs. Similarly, Litman [41] set 40 transport sustainability indicators with 16 goals and 4 sustainability pillars. Moreover, Dhakal and Oh [43] identified 57 sustainability indicators under eight categories to evaluate sustainability of a road infrastructure during planning, design, construction, maintenance, and improvement. An indicator can be associated with two or three sustainability pillars depending on various perspectives [47]. Therefore, having reviewed several literatures and experiences of other countries, sustainability indicators were developed (Table 3) in a view to achieve SRM in developing countries. In this study, 45 sustainability indicators under 10 categories and three themes (social, economic, and environmental) were formulated to improve sustainability of road maintenance practices.

3.4.3. Labor-Based Methods for Sustainable Road Maintenance. Although labor-based road maintenance methods have the potential to create employment in rural areas and can be financially competitive with equipment-based methods, both governments and private contractors have been hesitant to use them [15, 16, 20]. The bottlenecks affecting the use of labor-based road maintenance methods were relatively low payment rates, hectic supervision and essentially lack of government commitments to these programs [9, 11]. Despite some quality and productivity issues with labor-based methods, they can be used for construction and maintenance of smaller, technically less difficult rural road projects [9]. Moreover, labor-based methods relieve the need for foreign exchange as opposed to machine-based methods which demand large foreign currency to import machines.

Gravel roads are expected to lead as the most widely used transport system and relatively cheaper option for connecting rural areas in developing countries [37]. Maintenance activities of the constructed rural roads are however inadequate and access to rural areas is usually hindered by frequent damage of the roads [1, 18]. The inadequacy of road maintenance in rural areas can be overcome by employing the abundantly available labor force. The use of labor force in rural areas for road maintenance helps to increase design life of roads in addition to an employment opportunity created for the rural community. As a result, governments and relevant stakeholders need to improve the low labor wage and arrange special incentives so that labor workers can compete and operate in road maintenance contracts [16, 26].

To improve the quality of work and labor productivity from labor-based methods, it is also advisable to develop country level labor-based road maintenance working manuals and give on-job training to the workers involved in maintenance activities. With these improvements in place, it is highly likely that the labor-based methods can contribute to the realization of SRM practice in developing countries.

4. Conclusion

Labor-based methods were found to be viable option for conducting road construction and maintenance activities in developing countries. This is based on the result obtained from literature review of labor-based road construction and maintenance practices in developing countries and comparative cost analysis of EI, LI, and LBES road maintenance methods in Tigray region, northern Ethiopia. Furthermore, the following conclusions were drawn from the findings of this study.

(i) The lower units costs of EI and LI than LBES indicates that EI and LI methods are cheaper options than LBES for maintaining shoulder damage in asphalt roads.

(ii) The LBES road maintenance method is more economical for conducting roadside bush clearing than the EI and LI methods.

(iii) Higher share of labor costs in EI and LI than in LBES indicates that road maintenance using EI and LI methods creates job opportunities for laborers in addition to improving working condition of a road.

(iv) In this study, 45 suitability indicators under 10 categories and three themes (social, economic, and environmental) were developed to improve future road maintenance practices in developing countries. Therefore, it is recommended to use SRM practices to increase sustainability of road infrastructure in developing countries.

Data Availability

The data used for the research are available from the first author upon request (berhanegr@gmail.com).

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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