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Rural Roads –roles, challenges and solutions for Sub-Saharan Africa's sustainable development

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Abstract: Most of the low volume rural roads in Sub-Saharan Africa are unpaved. They are lifelines to the socio-economic factors and well-being of rural communities. In those countries, most of rural roads are made from lateritic or gravel soils. The major challenges that rural roads face in Sub-Saharan Africa include a lack of funding and a lack of engineering input during both construction and maintenance activities. For those reasons, rural roads are generally in poor condition and become nearly impassable during the rainy season due to erosion processes which severely damage them. The poor condition of rural roads has severe consequences on the economic transport of goods and services, and on the overall mobility of people, which hinders the country's development. This paper assesses the importance and challenges of rural roads in Sub-Saharan Africa. It then proposes an approach to mitigate erosion of those roads through the selection of good-quality and appropriate soils to use on the surface, construction with efficient drainage systems and regular road maintenance. Moreover, the impact of those roads on the sustainable development is highlighted.
Keywords: rural road, unpaved road, erosion, sustainable development, Sub-Saharan Africa

1. Background

Effective road transport systems are key to any country's development. The good condition of rural roads reflects enormous savings associated with reduced travel time, safety of passengers, and good and timely delivery of local produce. Road transport has become a basic human need for door-to-door aspects of communication and roads are on the priority list of infrastructure development. In Sub-Saharan Africa (SSA), rural roads are not only channels to access education, health and social services, but also help the smooth transfer of policies from central governments to the communities in rural areas.

Most rural roads in SSA are unpaved, with gravel and lateritic materials which form the surface layer of the road and are regularly exposed to varying weather conditions of wetting and drying. This exposure and the repeated traffic action leads to a quicker deterioration of rural roads, mainly due to rain and surface water flow erosion. Water erosion detaches surface soil particles and subsequently transports them as sediment down slopes. Wet roads with lowered soil strength promote the formation of rills due to traffic wheels, which hinders the already fragile rural transport systems of the SSA countries. In such conditions, there are palpable imbalances between the rate of deterioration and the available funds for both construction and maintenance of rural roads.

Consequently, only about 34% of the population in SSA have access to rural roads, compared to 90% in Asia and the Pacific, and 65% in other developing countries [1, 2]. While 37% of world's population have access to all-weather rural roads within 2 km [3], the SSA has the least access to such all-weather roads [2, 4, 5]. The importance of rural roads to communities justifies the constant need for their good conditions, without which the sustainable development of SSA could be jeopardised. However, the rural transport policies in SSA do not show how countries will increase the number of people accessing all-weather roads within 2 km up to 90%, to achieve the "leave none behind" target of the sustainable development goals in terms of transport [6]. This paper has adopted the approach of "identify problems – suggest solutions - talk of impacts" for rural roads in the SSA.

2. Problems of rural roads in SSA

2.1. Funding

The lack of funding for the development and maintenance of rural roads in SSA has been discussed in different studies [3-5, 7, 11]. The major sources of these funds include donor agencies and multilateral banks such as the European Union, the World Bank and the African Development Bank through support to the countries' budgets, and programs such as the Africa Community Access Program (AFCAP) and the Sub-Saharan Africa Transport Policy (SSATP). Those initiatives for rural roads' improvement have mainly targeted sector developments such as agriculture and market access, poverty reduction and social interactions, education and health services [3].

In reference [7] Petts argued that maintenance for road networks in developing countries should range from 0.2 to more than 1% of the gross domestic product (GDP), while the total road sector budget should range from 3 to 5% GDP, an amount which could be more than double the annual income in many SSA developing countries. For rural roads, the lack of a spending plan complicates the task. The spending plan in main roads is such that 65% of the budget is used for maintenance, 15% for rehabilitation and 20% for new constructions [5]. Therefore, governments risk undervaluing the rural roads' urgency, regardless of the huge detrimental consequences on the countries' economic development. Deplorably, the severe consequences are felt by women and children who cannot afford the thus imposed costlier modes of rural transport services [2].

Table 1 shows the percentages of unpaved roads in the ten poorest SSA countries. It can be seen that those countries rely on unpaved roads for mobility and access to communities, mainly in rural areas. The high portion of earth roads and their poor conditions in SSA [4, 5] affect the socio-economic and development factors, hence exacerbating poverty. Most surprising is that high percentages of unpaved roads also exist in richer countries of SSA, suggesting poor planning in the region. Table 2 shows that South Africa, Nigeria, Angola, Kenya and Tanzania have about 80% or more of unpaved roads; while the Arabic African countries such as Egypt, Algeria, Morocco and Sudan have smaller percentages of unpaved roads with 7.8%, 22.9%, 29.6% and 63.7% respectively.

Table 1. Unpaved road networks in 10 poorest countries of Sub-Saharan Africa [8]

Country	Area (km^2)	Population	Growth rate (%)	Total road network (km)	Unpaved roads (km)	% unpaved roads
Somalia	637,657	15,636,171	2.99	22,100	19,492	88.2
CAR(*)	622,984	4,825,711	1.86	20,278	18,893	93.2
DRC(**)	2,345,000	86,727,573	3.9	153,497	150,703	98.2
Burundi	27,834	11,575,964	3.21	12,322	10,822	87.8
Liberia	111,369	4,977,720	2.56	10,600	9,943	93.8
Niger	1,267,000	23,176,691	3.88	18,949	15,037	79.4
Malawi	118,484	19,718,743	2.89	15,450	11,413	73.9
Mozambique	801,590	31,408,823	2.88	31,083	23,718	76.3
Eritrea	117,369	5,309,659	2.35	4,010	3,136	78.2
Madagascar	587,041	26,969,642	2.69	37,476	31,373	83.7

(*) and (**) for Central African Republic and Democratic Republic of Congo respectively.

Table 2. Unpaved road networks in 10 wealthiest countries of Africa based on GDP2017 [8-10]

Country	Area (km^2)	Population in 2019	GDP (billion $)	Total road network (km)	Unpaved roads (km)	% of unpaved roads
Nigeria	923,768	200,962,417	376.284	193,200	164,220	85
South Africa	1,221,037	58,065,097	349.299	747,014	588,062	78.7
Egypt	1,001,449	101,168,745	237.037	137,430	10,688	7.8
Algeria	2,381,741	42,679,018	178.287	113,655	26,050	22.9
Angola	1,246,700	31,787,566	124.209	51,429	46,080	89.6
Morocco	446,550	36,635,156	109.824	58,395	17,279	29.6
Ethiopia	1,104,300	110,135,635	80.874	110,414	96,060	87
Kenya	580,367	52,214,791	79.511	161,452	147,032	91.1
Sudan	1,861,484	42,514,094	58.239	11,900	7,580	63.7
Tanzania	945,203	60,913,557	51.725	86,472	79,380	91.8

2.2. Low-level engineering input

The low level of engineering input in design, construction and maintenance is a serious challenge to rural roads in SSA. Recently, a systematic analysis of knowledge on erodibility of soils in rural roads was carried out at the University of Birmingham and one of the findings was that rural roads suffer significantly from gaps in engineering knowledge [11]. This causes hindrances in the selection of good material for construction, selection of adequate and low-cost equipment during both construction and maintenance, as well as necessary instructions for proper road use. According to reference [12], many rural roads in SSA are unnecessarily constructed using heavy equipment despite the opportunities to use labour-based and locally available technologies. Also, easy and small activities on rural road, which do not need a high level of skills are unjustifiably performed by expensive and international experts, regardless of limited funding available for those roads. While the research level on rural roads would support the availability of engineering input to those roads, the findings of the aforementioned study on erodibility of soils in rural roads [11], showed that Africa in general is very behind when it comes to research. Out of 219 studies that were analysed in detail, Africa was involved in only about 5% of erodibility studies for rural roads; a very unsatisfactory contribution when compared to Europe and America which were involved in 35.6% and 33.8% respectively (Fig.1). Furthermore, this is a problem which has more severe consequences in SSA than in any other part of the world.

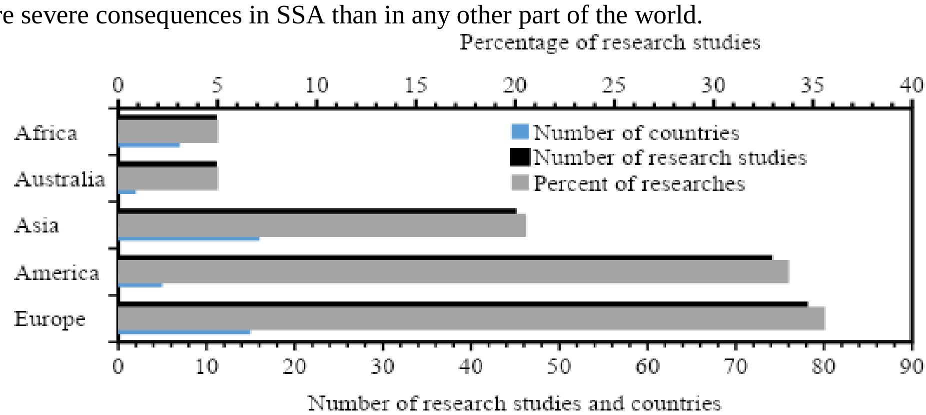

Fig. 1. Research on erodibility of soils in rural roads in various continents

2.3. Water erosion

Inter-rill (sheet) erosion

Sheet erosion in rural roads is a result of detachment of soil particles and their subsequent transport by raindrops and surface water flows. The particles are detached by rain drops and splash short distances, but the raindrops' kinetic energy controls the surface soil detachment even after a thin layer of surface water flow is formed. In the early stages of erosion, the flow may be without a defined direction and mostly affects the uppermost part of the road surface, but over a wide road area [13-19]. During sheet erosion, hydraulic shear stresses are minimal, and a good topsoil mass resistance would withstand erosive forces and minimize erosion effects.

Rill erosion

Rill erosion results from the sheet erosion's progression, which forms water flow paths - rills. The flow concentrates into rills to take discernible directions on the road surface. Usually, the narrow and shallow rills can be cleared by routine road maintenance activities using locally available tools [20, 21]. Contrary to sheet erosion, the rill erosion sediment transport is due to concentrated shear stresses that progressively detach soils and feed them into the flow system [22-25]. According to references [20] and [26], the rill sediment relies on runoff shear stresses which become greater than the critical shear stress necessary to detach soil materials in rills. From experience, researchers have reported that rill erosion is the highest sediment contributor from steep slopes, which causes deposits whenever the load sediment exceeds the rill's transport capacity [14, 27].

During erosion processes, two phenomena, namely entrainment and deposition are connected by a flow transport system. Entrainment concerns the mass of detached soils which leave a point of an earth road's surface due to erosion. In contrast, deposition is the soil mass that reaches and stays at a point of the road surface. Therefore, the net deposition at a given point on the road surface can be defined as the deposition when the entrainment from the same point is subtracted; while the opposite gives the net erosion. Less often, a state of equilibrium exists if both entrainment and deposition loads equate; although in reference [28] Cochrane and Flanagan argue that the flow conditions prefer either net detachment or net deposition. In rural roads, it is better to maintain the road before the surface rills grow into gullies for economical and fewer traffic interruption reasons.

Gully erosion

Gully erosion in rural roads is a continuation of rill erosion when maintenance is not properly carried out in a timely manner. Like rill erosion, gully erosion depends on concentrated hydraulic shear stresses. Ephemeral gullies are an early age of development and can be defined as a transition between rills and complete gullies, which are wide and deep [21]. For example, reference [29] reported gullies in Nigeria with depths up to 150 m, widths and lengths ranging from 0.4 m to 5.6 km and from 0.7 to 2.5 km respectively. Such big gullies are a real danger to the rural transport systems, but also to the community. In unpaved roads, Ziegler and Giambelluca reported in [30] about 1 m both wide and deep impassable gullies in Thailand; where as in [31] Jungerius et al., recommended the treatment of rills in unpaved roads before their development into gullies.

The analysis of 564 studies on erosion in different focus areas including agriculture, unpaved roads, dam engineering, vegetated and bare hilly slopes, has shown that gully, rill, inter-rill and splash erosion types generally dominate the topic (Fig. 2). About 15% of those studies were on unpaved roads, where the four mentioned types of erosion are more obvious and may produce up to 90% of total sediment in an area where those roads only occupy 0.05% of land use (Fig. 3).

Moreover, Fig.4 shows a typical road damage by water erosion due to poor or lack of drainage systems. Rainwater was not drained off the road's running surface, and created a rill which grew into an ephemeral gully along the length of the road. It is clear that maintenance activities have not taken place on time. However, if a further delay of maintenance occurs, the next rainfalls will lead to a fully developed gully with unacceptable depth and width, which will occupy the most part of the running surface and completely stop any traffic that could use the road.

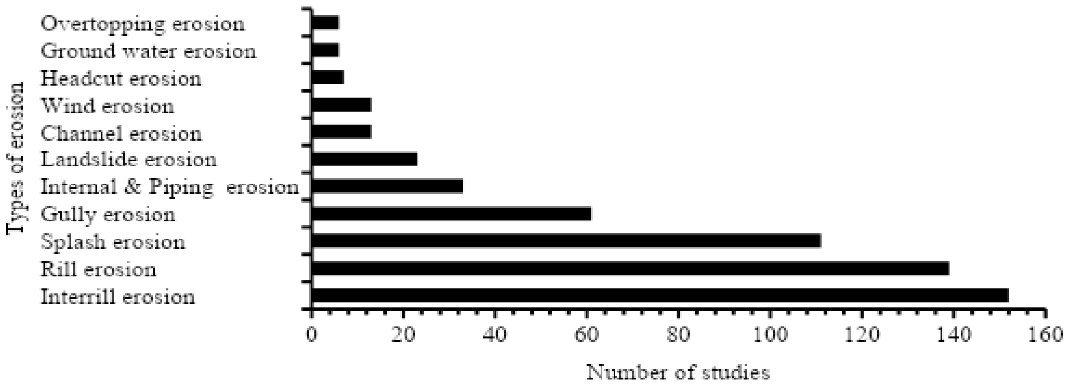

Fig. 2. Erosion studies on different land uses

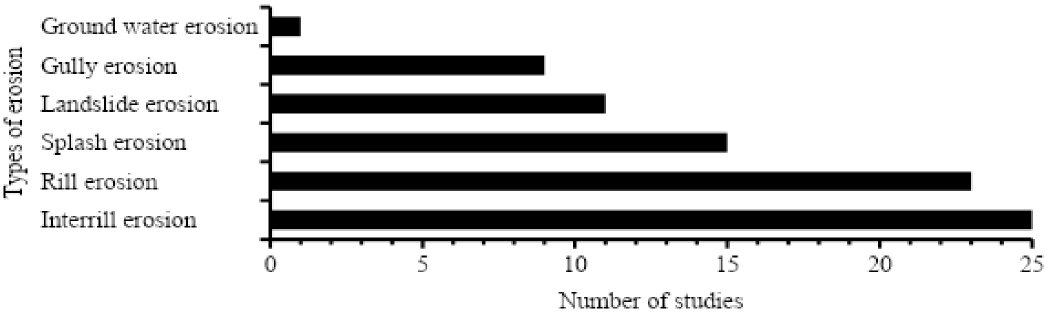

Fig. 3. Erosion studies on unpaved roads

Fig. 4. A rural lateritic road damaged by erosion in the Central African Republic. Accessible at https://www.naturepl.com/stock-photo-erosion-of-murram-road-after-rainstorm-in-wet-season-boukoko-village-image01409744.html

In addition to identifying water erosion as a major challenge to rural roads, the factors which can aggravate water erosion on those roads were also identified. These are grouped into three classes, namely geological and geotechnical factors; environment and climate factors; and road and traffic factors (Fig. 5); and have been discussed in other papers by the same authors [11].

Environment and Climate factors: precipitations, rain intensity, rain duration, raindrop size, raindrop shape, raindrop falling velocity, rain surface striking angle, weathering, flow stresses, water chemistry, freeze-thaw, humidity, wetting and dry cycles, slope properties and vegetation.

Road and Traffic factors: road cuts and fills, longitudinal drainage systems, cross-drainage systems, traffic volume and type, traffic speeds, traffic frequency, road geometry, road size, road drainage area, road surface roughness, and maintenance regimes.

Geological and Geotechnical factors: soil type, clay content, particle size distribution, shear strength, cohesion, bulk density, moisture content, maximum dry density, optimum moisture content, salts content, organic content, California Bearing Ratio, unconfined compressive strength, friction angle, consistency limits, aggregate stability, permeability, infiltration rate and infiltration capacity.

Fig. 5. Factors affecting erodibility of soils on unpaved rural roads

3. Solutions to combat erosion of soils on rural roads

3.1. Material selection

One of approaches to combat erosion of unpaved rural roads would be to select good-quality surface soil materials that can resist erosion. The SSA countries are rich in lateritic soils and many unpaved roads in this part of Africa are constructed using this soil type. The desired particle size distribution and properties for earth road surface materials, as proposed in this research, were decided based on the studies in [32-36]. Particularly, the lateritic soils' properties were selected based on works by [32, 33, 37, 38]. Additionally, those materials were tested for compaction ability using Andersen and Adreasen's modified model [39]; they show a self-compaction advantage and are therefore cost effective. The model is described in Equation 1:

$$P(D) = \left(\frac{D^q - D_{min}^q}{D_{max}^q - D_{min}^q}\right) \quad (1)$$

where $P(D)$stands for the cumulative percent finer than the particle size D;
D_{min} and D_{max} are the fixed minimum and maximum particle sizes of the material mix, and
q is a parameter such that $0 < q < 1$ but best when q is less than 0.5.

This model draws a line through an envelope bound by minimum and maximum particle size properties shown in Table 2. Moreover, the envelopes satisfy the requirements for good surface soils for use on the surface of unsealed roads which resist erosion, slips, ravels and corrugation failures [40]. The grading coefficient for these soils ranges from 16 to 34; while their shrinkage product is between 100 and 365. According to [35], these soils have the plasticity index of 2 to 10%. The particle size properties for good road surface soils are shown in

Table 2, with D_i the particle size corresponding to $i$percent finer. The coefficients of uniformity, Cu and the coefficient of curvature, Cc are given by Equations 2 and 3:

$$C_u = \frac{D_{60}}{D_{10}} \tag{2}$$

$$C_C = \frac{(D_{30})^2}{D_{10} * D_{60}} \tag{3}$$

Table 2. Important particle properties for earth road surface and lateritic soil material envelopes

	Surface soils [32-36]						Lateritic soils [32, 33, 37, 38]					
	D_{10}	D_{30}	D_{50}	D_{60}	C_U	C_C	D_{10}	D_{30}	D_{50}	D_{60}	C_U	C_C
Minimum (mm)	0.08	0.25	0.8	1.1	13.8	0.7	0.04	0.38	1.1	1.6	40	2.3
Maximum (mm)	0.4	1.8	4.9	6	15	1.4	0.6	6	10.5	14.5	24.2	4.1

3.2. Drainage efficiency and effectiveness

Failures of drainage systems can negatively impact on effective use of rural roads. When those roads are not provided with effective and efficient drainage systems, they fail to serve for the designed periods. The rain water will not be drained off the road surface immediately, erosion of surface soils will be huge and costly. Despite their importance, rural roads are sometimes the simple shaping of the ground (earth roads), with sometimes an additional layer of compacted granular soils (gravel roads). The drainage systems in rural roads are mostly open channels which may suffer from [33, 35]:

- Not being deep and wide enough to drain off water from the road surface effectively
- Poor distribution of cross drainage leading to overloading of longitudinal drainage systems
- Poor maintenance and hence becoming gullies due to water erosion, reducing the running surface width
- Being blocked by erosional deposits and grasses due to lack of adequate maintenance

3.3. Maintenance schemes

The maintenance of rural roads is a heavy burden on many African governments, who are not even able to adequately maintain the main roads. Although the maintenance of rural roads may only need the use of local labour and equipment, the lack of planning and/or funding impacts on the effectiveness of the maintenance [7]. Additionally, traffic wheel action and loading accelerate erosion in those roads [41-49] prompts the need for a quick maintenance response. Heavy traffic should be limited to minimise crumbling of surface soils, particularly during the wet and rainy seasons when rills are easily created and widened by traffic actions. An acceptable rural road maintenance diagram is proposed in Fig. 6.

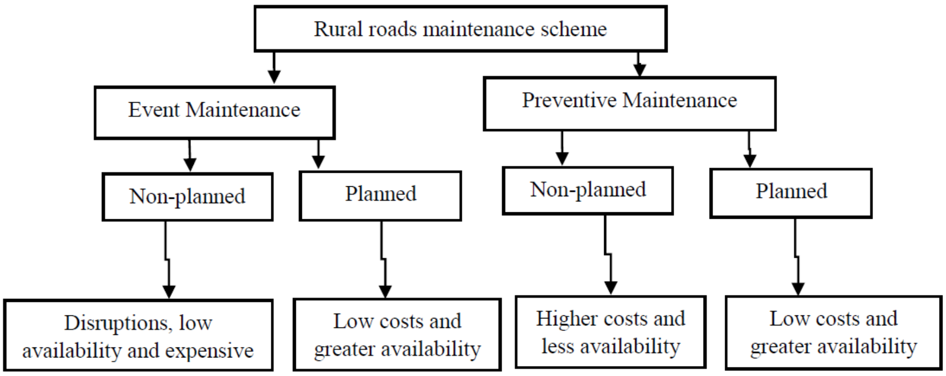

Fig. 6. Simplified unpaved rural roads' maintenance diagram

4. Rural roads' impact on the economy of SSA countries

Most of the SSA economies heavily depend on the agriculture sector [5, 7] and the good condition of rural roads contributes to the development of this sector. With poor rural road conditions, it is very difficult for the farmers to access their farms, transport fertilisers and even transport the produce to the local markets. To emphasize the importance of rural roads in the development of the agriculture sector, reference [5] stated that SSA farmers may feel unsupported if the physical barriers and costs for transporting produce to the nearby markets remain high. An example happened in Tanzania, where in 1988, the country lost 50% of its cotton harvest in three regions, 80% of its rice in one region and more than 50% of seeds, fertiliser and herbicides in another region due to poor rural road conditions [5].

While the agenda for poverty alleviation has become a constant slogan in SSA countries, both the UN and World Bank agree that about 54% of the SSA population are poor [50]. Rural roads can be catalysts for development transformation in those countries by providing low cost transport means for labourers, fertilisers and produce to the local markets, as well as job creation in rural areas. It is in this line that donors have stepped up to cooperate with the SSA governments in initiatives to improve rural transport. Reference [51] reported that the African Development Bank for example availed over 1 billion USD in 2007 and the World Bank invested more than 9 billion USD in 2010 in the construction and maintenance of rural roads in SSA. Countries also acted accordingly and the Kenyan government in 2011, invested 20% GDP, about 4 billion USD, in infrastructure development including the improvement of the then 93% unpaved rural roads of its 160,886 km road network. The impacts of such improvements in rural roads include but are not limited to poverty reduction, improved land use, family income generation and wellbeing, accessibility to health and education services, reduced transport costs, enhanced agriculture and market participation. For example, the Kenyan investment registered enhancements of 27% and 18% in transport to market and towns respectively, 37% and 8% in milk selling and production accordingly, and 57% in maize production [51].

Moreover, [52] reported that rural roads' improvements have increased the agricultural output by 27% in Ethiopia and improved prices of maize by 0.08% to 11.4% in Ghana. Similarly, income and consumption improvements were reported in about 78% of reviewed studies, with traffic flows being improved by 21% to 312% with a more than 50% reduction in travel costs; and furthermore, opportunities for growth of small and medium businesses have been noticed [52]. In another report, [53] stated that there was a poverty reduction of about 6.9% with a consumption growth of 16.3%. Additionally, [54] reported that rural roads strengthen the agriculture sector, which employs more than 50% of the SSA population, mainly women and youths, and contributes an average of 15% GDP; while a country like Chad gets its 50% GDP from agriculture. Overall, there is little chance for SSA countries to achieve sustainable development without improving the condition of rural roads constantly.

In addition to the impact of the good condition of rural roads on the agricultural sector, which is undeniably the key in SSA countries' context, those roads affect almost all the socio-economic and developmental factors of developing countries, as shown in Fig. 7. The positive and negative results of both good and poor conditions of rural roads on the life of people living in rural areas of the SSA countries are enormous and significantly affect the countries' sustainable development.

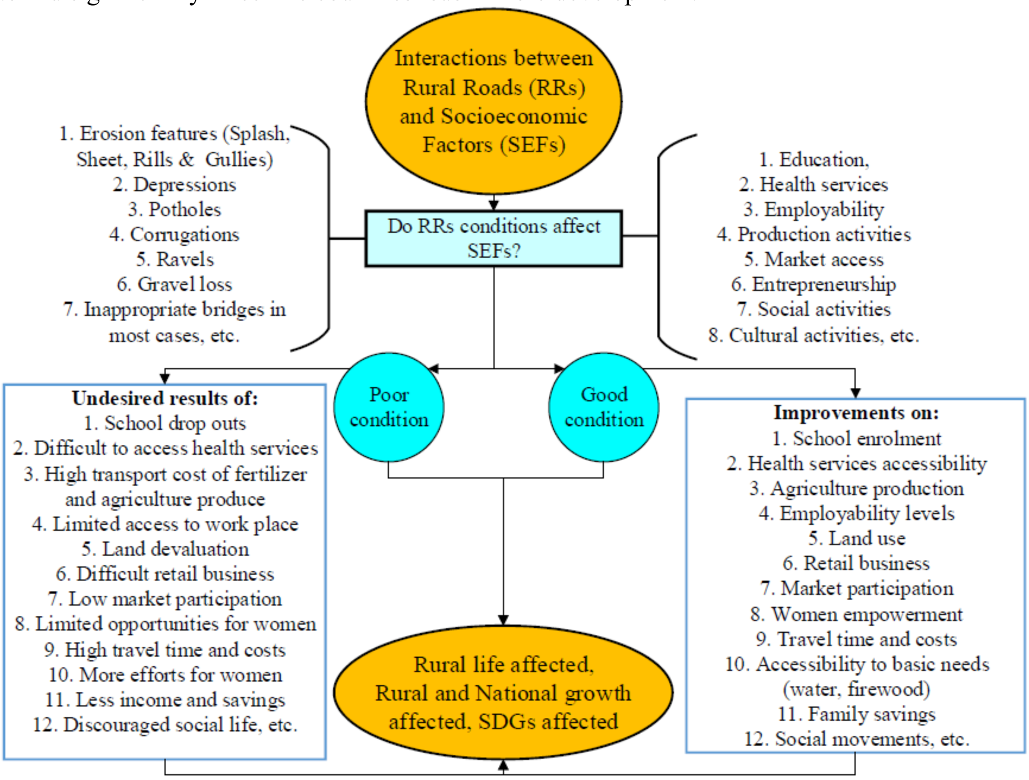

Fig.7. Summarised impact of rural road conditions on socio-economic factors and development

5. Conclusions

The SSA countries are among the least developed countries in the world. The poor rural transport systems in those countries only worsen their economic situation. However, it was found that by improving rural accessibility and mobility, countries would better achieve the sustainable development. Improved rural transport systems help to develop the agriculture sector as the main source of income and the baseline to the SSA's life. Access to education and health services, market participation, enhancement for small and medium scale businesses, job opportunities and women empowerment to mention but a few, are all improved if rural transport systems are in good condition. This paper has explored pertinent problems of rural roads, notably lack of funding and engineering input, with a focus on erodibility of the rural roads. Solutions for establishing less erodible rural roads have been suggested, including the careful selection of soils to be used on the surface of unpaved roads; construction with provision of effective and efficient drainage systems; and appropriate maintenance schemes. Finally, improved rural transport effects on socio-economic development have been outlined, with indications that this could be a better way to approach sustainable development in SSA countries.

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