2017

Creating Resilience Dividends with Road Water Management

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1. Introduction – Roads as instrument for resilience

It is a simple concept: resilience, improving existing systems, making them more productive and stronger, better able to deal with shocks and even converting problems into opportunities.

Resilience is a departure from the concept of 'sustainability' that aims to preserve what is there or prolong what has been newly created – and as such is often conservative by character. Yet development is a lifelong project, even though nature and culture are always changing. There is no cut-off date by which all is secured against all that comes after. It is here that resilience arrives – working with existing systems - make them more robust, fair and productive to provide inclusive services and reduce the vulnerability of those that live by them.

The benefit of resilience is captured in the concept of the 'resilience dividend' – elaborated by (Rodin, 2014). The resilience dividend compares the direct costs of damage and that of restoring damage with the costs of investing in resilience that is meant to minimize the damage from crisis events. Resilience is defined "*the capacity to bounce back from a crisis, learn from it, and achieve revitalization*". Apart from the ability to respond to shocks, there is the added benefit of 'revitalization'. This falls in a pattern: in many cases by making a system more resilient we create other benefits beyond those of direct risk management. This double-edge is further elaborated by (Tanner, et al., 2015), who make the point of 'a triple resilience dividend'. These three dividends concern (1) the avoidance or reduction of losses that occur when disasters strike; (2) the unlocking the economic potential by making areas, systems and infrastructure safer (3) co-benefits beyond reduced risk from the specific investment. Thus, the resilience dividend is more than the benefit of substituting crisis management with risk management but concerns other benefits too that are "good for wealth, well-being, profit, growth and development" (Tanner, et al., 2015).

This paper is an attempt to quantify the resilience dividend from 'roads for water', using data from monitoring a large-scale roads for water program implemented in Ethiopia and also undertaken in Kenya and Uganda. In addition, general data on asset management in road infrastructure are used.

The basic idea of 'roads for water' is to make roads instruments of beneficial water management and resilience. Roads have a major imprint on hydrology. They are a major human endeavor with a large impact on water management. Roads block water, guide water, concentrate the run-off in limited drainage canals and affect sub-surface streams. Ibisch et al. (2016) have described the fragmentation of landscapes (and as well as the drainage basins) that has come with road development. They further established that by now 20% of the global land surface is within one kilometer of a road. The remaining 80% is divided into approximately 600,000 patches – more than 50% of which are less than one 1 km2 and only 7% of which are larger than 100 km2. To manage surface and sub-surface hydrology hence means increasingly managing roads (and to safeguard the remaining 'road-less' areas).

The impact of roads on landscapes and surface hydrology is often negative. Roads cause erosion, trigger sedimentation and cause local flooding. Road bodies are a main reason for drainage congestion and water logging. They disturb wetland hydrology and interfere with fish movement in flood plains. Roads could also initiate landslides. Transect surveys along roads undertaken in upland Ethiopia and Uganda showed that in every 10 kilometer of roads there are between 8 to 25 problem spots. Data from two coastal polders in Bangladesh show that 60% of farmers are affected by impeded drainage due to roads.

Figure 1 negative impacts of roads on its immediate landscape. Flooding, erosion and sedimentation are main problems.

This impact of roads on the surrounding landscape is not going to diminish. An estimated 900 Million rural people still did not have access to roads and transport infrastructure in 2006, defined as the population living with 2 kilometers distance from an all-weather road. Sub Saharan Africa scored particularly low with the rural access index standing at 30% (Roberts, KC, & Rastogi, 2006). It is predicted that roads and railways in all continents will increase significantly to 2050. One estimate is that nearly 25 Million paved road lane-kilometers and 335,000 rail track kilometers will be added from 2010 to 2050 - a 60% increase (Dulac, 2013).The cost of this infrastructure will be approximately $45 Trillion USD over the period. To this the expansion of unpaved road network may be added. When combined with reconstruction/upgrade costs and annual operation and maintenance spending, global transport expenditures are expected to approach USD 3 Trillion per year over the next 40 years. Roads are also essential for improved rural transport and this drives inclusive growth. Rural road infrastructure promotes social cohesion and connectivity and has key links to meeting the challenge of the Sustainable Development Goals in trade, education, health and jobs.

2. The resilience dividend with roads for water

There are a large number of measures that can be taken to manage water with roads and with it to manage roads with water and make roads instruments for resilience. Road bodies can be used to harvest water in dry areas guiding the water intercepted by the roads to recharge areas, surface storages or to apply it directly on the land. With the enormous lengths of roads being built, roads in many semi-arid areas present the main opportunity for water harvesting and buffer management. Roads can also be used to manage water catchments – controlling the speed of run-off, compartmentalising and mitigating flood run-off and influencing the sedimentation process in the catchments. In flood plains and in coastal areas roads can have a role in flood protection – doubling up as embankments and providing flood shelters. Further, in low-lying wetland areas and floodplains roads and bridges affect the shallow groundwater tables and the way a road is built and for instance the height of bridge sills and culverts will have considerable influence on the quality of the wetland on either side of the road. Because of the sheer magnitude of road building programs, the scope of making a positive contribution to water management is enormous. In some instances additional measures may suffice; in other instances the design of the roads may be modified to better serve water management functions.

In most of such 'roads for water' applications there are multiple resilience wins. In this paper we will focus on one particular application of roads for water – I.e. using roads for harvesting water in semi-arid areas. This follows from the large-scale implementation of roads for water programs in the four main regions in Ethiopia. In the country road development was a major source of erosion, sedimentation, water logging and flooding, but with the introduction of the different measures since 2014 these trends started to reverse (Puertas, et al., 2014).

Figure 2 Examples of road water management techniques

By making roads that can serve several additional purposes beyond transport and by making these part of the design and development of roads, it is possible to create roads that (1) reduce the now often substantial collateral damage that uncontrolled road water does to the landscape around it; (2) are likely to have lower maintenance costs and down-time and are generally better able to withstand weather effects including those that are caused by climate change; and (3) generate substantial benefits in terms of water harvested with the roads and other beneficial water management functions. In other words rather than being a source of landscape degradation, can become instruments for climate change resilience. These triple dividends using the framework of (Tanner, et al., 2015) are summarized in table 1.

Table 1 Triple resilience dividends of the 'Roads for Water approach" in Ethiopia

	Resilience	Impact
1	Reduced damage in the wake of disaster and unusual events	Reduced cost of road maintenance
		Reduced damage due to erosion
		Reduced damage due to flooding
		Reduced damage due to sedimentation
2	Unlocking the economic potential	Less down time of roads
3	Co-benefits	Beneficial use of water harvested from roads

Section 2 of the paper calculates these three types of resilience benefits, making use of monitoring data from the roads for water program in Ethiopia. This has been implemented since 2014 – initiated as a catalyst research project under the UPGro Program (NERC, UK), but almost immediately picked up and going to scale, and next further supported by the NWO/WOTRO (The Netherlands) and by the Global Resilience Partnership. Under the leadership of several regional governments and with encouragement of the Ethiopian Roads Authority the program was implemented by the regional agriculture and rural development offices as part of the watershed mass mobilization campaigns. A wide array of road-related water harvesting measures were implemented: flood water spreaders, road-side infiltration trenches, road-water storage ponds and converted borrow pits, water diverters from culverts besides the promotion of road-side tree planting as well. The number of labor days involved over two seasons in the program in Tigray, Amhara, Oromyia and Southern Nations is estimated at 40 Million labour days and the number of persons who benefitted in access of 2 Million. The different resilience benefits are given in table 1 are discussed respectively in section 2.1 to 2.3.

Section 3 makes a comparison with an alternative road resilience approach. Rather than creating resilience by making roads as instruments for water management and resilient landscapes – a more defensive approach is taken. In this narrow approach the emphasis is on making the road infrastructure itself more resilient and disaster proof – typically by applying heavier design specifications but with no attention for the impact on the surrounding area. The paper concludes with section 4 discussing the scope to take the Roads for Water approach further forward.

2.1 The first dividend: reduced damage to the landscape

The first 'pay-out' of the roads for water approach is the reduced damage to the landscape surrounding the road [Table 2]. This damage from roads is often substantial. In several areas roads are a major contributor to landscape damage, i.e. the disturbed hydrology of wetlands, the accelerated formation of sand dunes in desert areas and in many semi-arid areas: erosion, gully formation, sedimentation, flooding and water logging along roads. It is not just only damage caused by abrupt shocks: much is due to the incessant impact of uncontrolled road drainage on the surrounding landscape. The associated costs are made up of the several interlinked components, discussed and assessed in this section.

Table 2: Summary of financial Impacts to landscape

General costs	Specific	Possible resilience dividend (USD/Km/Year)	Source
Cost of gullying and erosion	Loss of land for farming	216	(FAO, 2017)
	Loss of soil moisture adjacent to gullies	366	(Woldearegay, Steenbergen, Agujetas, Grum, & Beusekom, 2015)
	Loss of nutrient rich soil	33	(Ayele, et al., 2015)
	Value of lost land	2,060	(Oruonye, 2015)
Cost of sedimen-tation	Silting up of water infrastructure	180	(Woldearegay, Puertas, Steenbergen, Beusekom, & Agujetas, 2014)
	Effect on aquatic life		
	Sand deposits on agricultural land		
Cost of flooding	Damage to houses and public infrastructure	262	(Woldearegay, Puertas, Steenbergen, Beusekom, & Agujetas, 2014)
	Flooding of agricultural land – loss of crops	750	Monitoring
Cost of water logging	Water logging of agricultural land	750	Monitoring
	Total	4617	

Erosion and gully formation

What roads do is that they change run-off patterns. Where rain run-off prior to the road development would flow in a widely dispersed manner, it is now bundled in a small number of drainage routes, guided by the road bodies and drainage structures. This has a large bearing on the area immediately downslope from road that was not used to carry so much water ((Moeyersons, 1991) (Makanzu, Dewitte, Ntombi, & Moeyersons, 2014).. When not taken care off, these more intense flows will cause erosion and trigger the formation of gullies. Particularly where soils are soft and land is already eroded, gullies can be long and deep, ripping through agricultural land and causing a loss of soil and nutrients, consequently land degradation.

Several studies in Tigray and Amhara, including the monitoring of the Roads for Water program, assessed the dimensions of gullies created by uncontrolled road water drainage (Addisu, 2011) (Woldearegay, Puertas, Steenbergen, Beusekom, & Agujetas, 2014). The measurements correspond to the findings elsewhere (Makanzu et al., 2014). The studies established that such gullies have a mean length of 530 meters a width of 9 m and depth of 1 m. Transect surveys recorded by Woldearegay et al. (2015) estimated that in Ethiopia a road could produce on average one problematic gully per kilometre. Based on these figures per kilometre of road, 4770 m^2 of land may be lost due to roadside erosion. Based on the lost yield, this represents a monetary value of lost potential of USD 216 km/year in terms of lost agricultural opportunity[1] due to this land loss. The value of the land affected by gully formation is estimated at USD 2,060 [2] using 2014 proxy prices. The cost of land is in fact may be expected to be higher when adjacent to the road as due the access it provides to markets and services. (Torbjorn & Bharat P, 2012) (Oruonye, 2015).

Gullies also have a significant effect on the soil moisture content of the land immediately adjacent to the road – described as 'bleeding'. When there is a gully the soil moisture of the land adjacent to the gully is depleted. Monitoring of moisture distribution along a road gully in Freweign area, Tigray, Northern Ethiopia, showed that the soil was nearly dry (5% moisture) adjacent to the road. This increased gradually to 20% and 40% moisture at respectively 5 and 10 meters distance. The depth of sampling was 0.5m and the soil type in the site was silty sand. Samples were collected one day after a 50mmf this impact can constitute a loss of USD 366 per kilometre[3].

Apart from the spectacular manifestation in gullies, roadside erosion often occurs in the gradual form of wash out all along the road section. This constant roadside erosion also leads to the loss of soil and vital nutrients – particularly nitrogen and phosphorus. (Ayele, et al., 2015) estimates that the related loss of topsoil and subsoil represents a value of USD 69 per hectare per year[4]. Per kilometre the cost of gradual loss maybe estimated as USD 33.

Sedimentation

A second major landscape impact from roads is sedimentation. One source of sedimentation is from the roadside gullies that open up after a road is constructed, as discussed above. Sedimentation is also caused in general by the change in surface run-off. A third source of sedimentation are the unpaved road surfaces itself – where the bed material is incessantly washed away, particularly if the road is not provided with water breaks or rolling dips that prevent the accelerated erosive run-off along the road service. The volume of sediment that is produced by roads can vary and is determined by road geometry, specifications, maintenance, soil properties and vegetation cover (Forman & Alexander, 1998).

Studies that quantify this effect are few. The limited studies however show that the impact is significant. Based on the Winooski River and Mad River watersheds in the relatively pristine Lake Champlain Basin in Canada, Wemple (2013) established that 24% or 10,388 kg/km^2/year of sedimentation could be attributed to the impact of road drainage and erosion of the surface of

[1] Damage was estimated to be 4770m^2 per km based on reconnaissance report and transect study on gully erosion. In terms of lost opportunity cost, the impact was around USD 216 km/year, based on average prices of wheat, maize and sorghum from various markets around Africa which value 100kg at USD 35 (FAO, 2015- 2017) and when 1 hectare produces on average 1,31 ton based on cereal and legume yields (Woldearegay, Puertas, et al. 2014). We opted for a conservative estimate, using the cultivation of a staple crop – not of high value horticultural crops.

[2] Plot of land in Nigeria is worth USD 4320 per hectare (Oruonye 2015).

[3] Study from Tigray (Woldearegay, et al. 2015) found there is around 85% less moisture content less than 5 meters compared with 10m and 50% less between 5-10 meters. Based on these figures and assuming that the area is dominated by rain fed agriculture then it can be assumed than anything within 5 meters of the gully loses next to full productivity. Considering an average gully of 530 meters in length per kilometer, a total area of 5,300m^2/km is lost between 0-5 m and an area of 5,3000 between 5-10 m loses 50% of its productivity. Based on FAO wheat and maize prices (FAO 2017), this accounts for a loss of USD 366 per km per year.

[4] Such erosion is affected by quantity of culverts, gradient of road, slope and soil type.

unpaved roads. When normalized to road length, Wemple estimated that that 8,294kg of sediment was produced annually per kilometre. Similarly monitoring data from Haywood County in North Carolina (USA) indicate that road surface and road embankments are a main contributor to sedimentation in the catchment, amounting to 32-37% of all sediment loads, only surpassed by the erosion of stream banks. These are all data from non-vulnerable watersheds, however. A different picture emerges from degraded watersheds: though road induced sedimentation is less in percentage of the total, it is vastly more in total volume. In Baringo District of Kenya, an area regarded as one of the most degraded in Kenya, unpaved roads contributed 12.5% of all sediment released (Bryan & Schnabel, 1994), When using erosion levels of 18 t/ha/year (Hurni, et al., 2015)[5], sediment contribution from unpaved roads can be as much as 3,600 t/km/year.

This huge movement of sediment has several effects. First, lakes and reservoirs may prematurely lose their storage capacity. This will affect power generation and domestic and agricultural water supplies (Mekonnen at al., 2015; (Wolancho, 2012). The impact of sedimentation of reservoirs in Ethiopia has already reached the point where it is starting to attribute to power-cuts (Tamene, Park, Dikau, & Vlek, 2006). Particularly, where the catchment has deep erodible soils and fierce rainfall events, the inconsiderate development of rural roads may spell disaster. A study on the Grand Ethiopian Renaissance Dam Basin calculated that implementing additional land conservation structures (such as those included in road water harvesting) in cropland on slopes > 8 per cent could reduce overall net erosion in all land cover classes by 21 per cent, and net erosion in cropland by as much as 43 per cent. This would mean a reduction from –320 million tonnes/yr to –251 million tonnes/yr (Hurni, et al., 2015).

Furthermore, sediment is also deposited on land and in drains. This may spoil the quality of land and block the drains. Sometimes this sediment can be turned into an asset and be collected for building material, but much depends on the location and the gradation of the road drainage system. This can be taken into account in road development though. Overall, impacts from road induced sedimentation are hard to quantify and can vary with the biophysical environment. However some impacts are included in this study. A recent transect survey looking at a 67km stretch of road from the highlands in Tigray, where high levels of erosion are common due to silty soil types found that road induced sedimentation had led to the silting up of 4 ponds[6] at a cost of USD 9,600 and 5 shallow wells at a cost of USD 2500[7]. This value translates to USD 292 per kilometre.

Flooding

The third damage caused by roads is flooding. This causes damage to houses and other build up infrastructure; damage to land that has been prepared but is flooded. It also causes loss of livestock and roadside trees. Ayele et al., 2015 found that significant damages due to animals being trapped inside gullies during the rainy season and privately owned commercial trees such as *Eucalyptus* and *Rhamnus Prinoides* being washed away. Ayele et al (2015) valued the loss of animals from one gully at USD 600 based on their sales price. The loss of trees led to a lost income of USD 201

A closely related phenomenon is water logging, whereby water remains standing upslope along the road body making it difficult to use the adjacent land. Transect surveys in Tigray in Ethiopia found that along 10 kilometres of roads there on average 13 to 25 flash spots. In 15% of these there is flooding of houses and land. In 30% of the cases there is persistent waterlogging and the remainder of the flash

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[5] In extreme cases this can go up to 400 t/ha/year.
[6] Assuming a typical roadside retention pond 4m deep, 10 wide and 15 long and a construction costs of USD 4 per m^3 (Desta et al., 2005) and daily wage of USD 10 (Cervigni et al., 2016)
[7] Cost of a hand-dug well is USD 500 http://smartcentregroup.com/wp-content/uploads/2015/09/SMARTech-Catalogue-Vrs.-3.-July-2016-1.pdf

point concerns gullying and erosion. A socio-economic survey that interviewed 322 respondents conducted in the Tigray and Amhara regions of Ethiopia found that 41% of farmers were impacted within a 500 meters on both sides of the road due to flooding and waterlogging. Based on their response, these damages of land led to a lost income of around USD 54 per year. Using this as a basis and considering that on average a farmer cultivates 1.5 hectare of land – meaning in 1 kilometre a total of 27 farmers are impacted by water, (Woldearegay, Puertas, Steenbergen, Beusekom, & Agujetas, 2014) a kilometre of road can inflict a cost of roughly USD 1,500 per year due to flooding and water logging. The study found that within 2 years of the road being built, yields had dropped by 40%. However, through interventions in road water harvesting the impact was dramatically turned around and within 1 year was up by 35% on the year of road construction. Further to the cost of flooding is possible damage to infrastructure. Woldearegay et al., (2014) observed that 8 houses from a study in Tigray, Ethiopia that had been damaged due to road induced flooding, which came in at a cost of USD 262[8].

2.2 The second dividend: the unlocked economic potential

The second dividend concerns the unlocking of economic potential that comes with larger resilience. In case of roads for water, this concerns the lower down time of roads and the reduced cost of maintenance of roads. In Ethiopia, for example, access to all-season roads increases consumption growth by 16% and reduces the incidence of poverty by 6.7% (Starkey and Hine, 2014). While in, Uganda, rehabilitation of more than 200 rural roads resulted in increases of proportion of marketed agricultural produce by 7.5%, farm gate prices by 36%, household income by 40%, and a reduction of post-harvest losses by approximately 20%.

Figure 3 farmers constructing temporary dam structure in trench, created by road departments, to irrigate adjoining paddy rice field with flooding method.

Down time and maintenance costs of roads are closely related. Geddes (2016) describes that road asset management is almost generally underfunded – but certainly so for unpaved feeder roads. Data from the Bureau of Construction, Roads and Transport in Tigray for instance from 1998 to 2015 illustrate this. In this seventeen years period the costs spent on maintenance reached 30% of the required level only twice. In all other years expenditures were less than 10% of the norm. The challenge of rural road maintenance will not diminish as networks expand. This challenge directly translates into

8 Typical construction cost of a rural household valued at 2,200

insecure accessibility of the more remote places (Kopp, Block, & Limi, 2014). Any approach that can reduce the maintenance costs of roads, especially feeder roads and community roads will make a difference. Compared to other parts of the world, road maintenance in Sub Saharan Africa amounts to a relatively larger part of GDP (1.8%) – constituting a considerable fiscal burden (Gwilliam et al. 2011). Second, even with these proportionally high allocations, the resources for road maintenance are low. Within road budgets maintenance is particularly under resourced: amounting to typically only 30% of road budget against a norm of 50%. A third factor affecting the level of maintenance on the ground is that even with the existing low budget provisions, typically not more than 60% of the financial allocation are actually spent. This is related to factors such as limited contractor capacity and unwieldy work procedures – with for instance short time intervals in the financial year available to undertaken the actual work (Gwilliam et al. (2011).

On average, however, about 34 percent of the entire road networks is in good condition, a further 27 percent is in fair condition, and the remaining 39 percent is in poor condition- needing immediate rehabilitation. For Ethiopia the figures are 38%; 28% and 34%. The burden comes down most heavy on the secondary and tertiary networks.

All these are arguments to come to roads that are resilient and relatively maintenance free. Approaches where water management is integrated in road development may make a considerable contribution in this regard. Much of the damage to roads is caused by water – intense precipitation, flooding and huge run-off. A commonly used estimate is that for unpaved roads, the damage caused by water is around 80% (Chinowsky & Arndt, 2012) and for paved roads the proportion is 30%. This amounts to USD 40,000 per km/year for paved road (AFDB, 2014). For unpaved roads the figure is around USD 3,000 per km/year.

In terms of maintenance, capital spending of countries is on average around USD 1,100 per kilometer per year on rural networks. This figure is around double for the main networks at USD 2,200 per kilometer. The figures vary significantly meaning that in some cases countries spend more on their rural road networks than others on their main networks. However, overall, nations that spend a higher amount on main networks also do so on rural networks and vice versa. Periodic maintenance can reach much higher figures however and usually take place every 5-6 years (Gwilliam, et al., 2011). For paved roads, – periodic maintenance can cost USD 68,000 per kilometer (AFDB, 2014) – with USD 20,400 of this due to water. The cost saving by better water management would amount to around USD 3,400 a year (assuming maintenance takes place every six years). Re-graveling on unpaved roads averages at USD 14,000 – USD 11,200 due to water. There would be a cost saving of USD 1,870 a year because of better water management, if we assume that a road need gravelling every six years.

Table 3 Describing climate change impacts on roads (Cervigni, Losos, Chinowsky, & Nuemann, 2016)

Paved Roads	Unpaved Roads
Temperature	
Accelerating age of binder	No significant impact
Rutting of asphalt and bleeding/flushing of seals	
Precipitation	**Precipitation**
Increasing moisture in subgrade layers and reduced load-carrying capacity	Increases roughness of road surface, increase average moisture in subgrade layers and reduced load carrying capacity.
Flooding	**Flooding**
Washing away and overtopping of roads	Washing away and overtopping of roads

Cervigini et al (2016) estimated the increased cost of the climate-change related damages for a future network of 2.8 Million kilometers of roads in Sub Saharan Africa (72% of which was unpaved) for a period of 35 years with a 6% discount rate. Their analysis shows that even under mean projections of a changing climate, costs are likely to rise significantly. Under climate change projection the costs of maintenance caused by precipitation and flooding will be USD 350 and USD 200 per kilometer respectively per year – or USD 550 per kilometer. This is an almost doubling of historical maintenance costs at USD 300, caused by precipitation damage of USD 200 and flood damage of USD 100.[9]

As road conditions are under pressure due to a changing climate, the 'downtime' of roads whilst being disrupted is likely to increase. Disruption time will affect the movement of goods and people. An analysis of the costs involved in this is presented in table 4 below. In a No Climate Change situation the loss to the economy because of road disruption may amount to USD 400 per kilometer per year for unpaved roads and USD 2326 per year for paved roads. Unless special resilience measures are taken, the average disruption costs from precipitation and flooding for unpaved and paved roads respectively will go up to USD 510 and USD 3290 per kilometer due to climate change (see table 4).

Table 4 Disruption costs per km under current and mean climate change (Cervigni, Losos, Chinowsky, & Nuemann, 2016)

No climate change	Paved	Precipitation	USD2300
		Flooding	USD26
	Unpaved	Precipitation	USD360
		Flooding	USD40
Mean climate change	Paved	Precipitation	USD2900
		Flooding	USD390
	Unpaved	Precipitation	USD450
		Flooding	USD60

Efficient control and disposal of run-off water on roads is key in ensuring maintenance costs. The Roads for Water modifications as implemented in Ethiopia come at modest costs of around USD1,800 per km. If included in the design of the road from the start is estimated they would amount to at a maximum of 2-8% of original investments planned for the road.

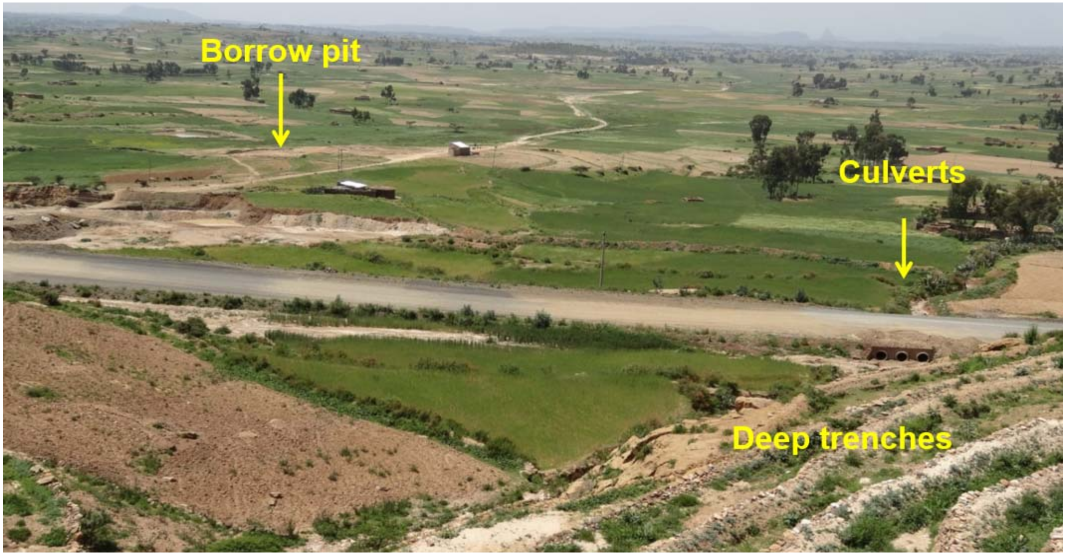

Figure 4 Road infrastructure is used to facilitate water retention and collection

[9] Cost are based on average for SSA and calculated Through the Infrastructure Planning Support System model. Model looks at the future impacts of climate change taking in expertise from various disciplines.

2.3 Third resilience dividend: beneficial use of road water and road infrastructure

The third resilience dividend concerns the beneficial use of road water. This primarily concerns the rain run-off that is guided by road bodies – with roads typically acting either as an embankment or a drain for the water falling in the landscape. As such roads in semi-arid areas like Ethiopia determine where water can be harvested and droughts alleviated. Droughts are recurrent in Ethiopia and other parts of the Horn of Africa (Taylor, Markandya, Droogers, & Rugumayo, 2014) . They are the most impactful of all human disasters (Wilhite, 2000) (Carlowicz, 1996). This situation may become more precarious: for Ethiopia for instance a temperature increase of 3.4 °C, is predicted by 2080 (NMA, 2007) and population growth is steady. Land degradation remains a threat in many parts of the country (Symeonakis & Drake, 2004).

Yet this trend is being impressively countered by massive investments in water and soil conservation measures throughout the country for the last ten years. Under the so-called mass mobilization programs adults provide 20 to 40 days of voluntary labor in the off-season. To this labour contributions under safety net programs are added. The widespread construction of rural roads in Ethiopia similarly has offered a major opportunity to harvest water and this has now been fully included in the watershed program in the four main regions of Ethiopia, benefitting more than 2 Million people. The different water related impacts of the harvesting of water with roads were monitored in Tigray.

Increased soil moisture and groundwater levels

First, the effect on increased soil moisture from systematic road water harvesting has been measured over the years in ten locations. The 'co-benefit' resilience dividend can be calculated from this. In general the effect of the road water harvesting measures implemented in Ethiopia is significant up to 100 meters from the down-side of the road, meaning that within a distance of 1 kilometre, soil moisture can be enhanced in an area of 10 hectares per kilometre. The significance is high in areas under rain-fed agriculture: reliable soil moisture is the driver for high yields. Whereas 86% of African soils are under soil moisture stress (Liniger, Mekdachi, Hauert, & Gurtner, 2011) studies show typical increases in soil moisture of 20% due to water harvesting (Grum, et al., 2016). Figure 1, based on four years of monitoring showed the increase in soil moisture in the Megab area in Tigray, Ethiopia during the critical October-November period when there is no significant rainfall. Road water harvesting has increased soil moisture considerably since it was introduced in 2014. The effect depended also on the total rainfall in the particular year. Importantly, 2014 was a consecutive year of below average rainfall and 2015 an extremely dry El Nino year, but even so there was an increase in soil moisture. In areas of rain fed agriculture the value of secure soil moisture from road water harvesting is assessed as USD4,500 per km/year[10] due the increase cultivation potential.

[10] Calculation assumes soil moisture recharge in an area of 10 hectares per kilometer in areas of rain-fed agriculture allowing for year round productivity, which otherwise would have suffered crop failure due to poor soil moisture conditions. Calculation based on average prices of wheat and maize in Mekelle, Ethiopia (FAO 2017) where 1ha=13.1quintal, 1 ha=USD450.

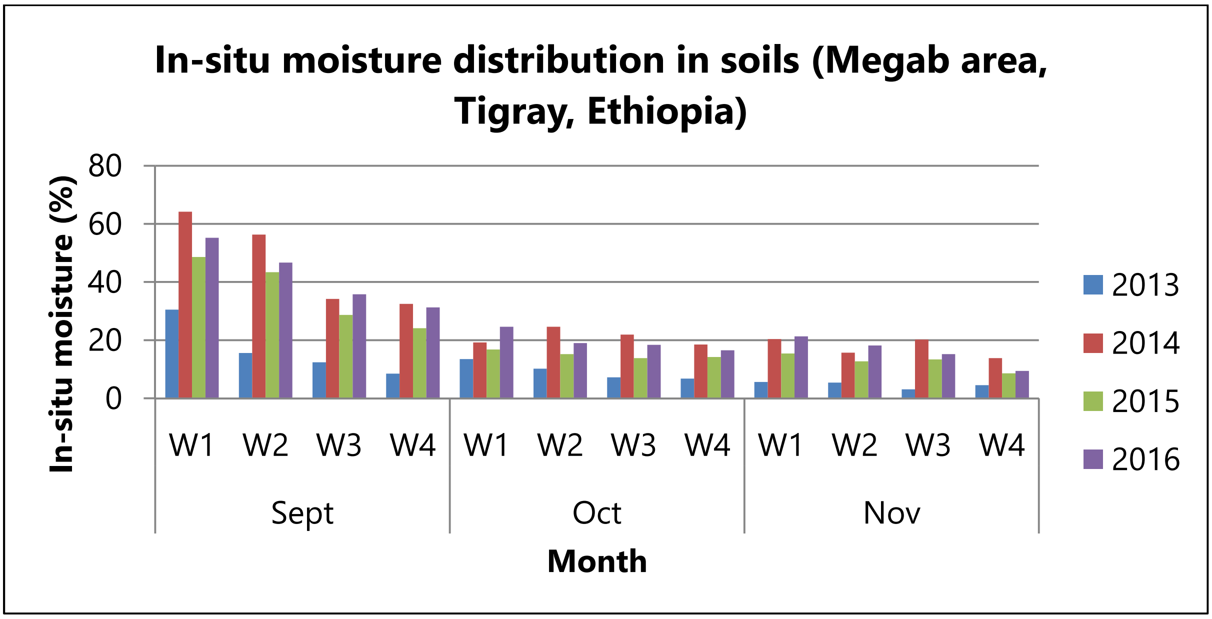

Figure 5 In-situ moisture distribution in soils

Note: In-situ moisture distribution in soils which are sandy clay to loam soils (before and after the construction of deep trenches at downstream of culverts in Megab area, Tigray, Ethiopia. Construction of the deep trench was done on June 2014. Monitoring was done for the period September-November for the years 2013 to 2016. (W1= Week one; W2=Week two; W3=Week three and W4=Week four.

Apart from the effects on soil moisture, road water harvesting increases local groundwater levels and can feed local hand-dug and tubewells from where communities can extract water during the dry season. This is a more resilient strategy because unlike soil moisture groundwater will be available over the years. Water harvesting with groundwater recharge is key in boosting agricultural production and reducing vulnerability (Mutekwa & Kusangaya, 2006); (Dile, Karlsberg, Temesgen, & Rockström, 2013) (Shah, 2010). Monitoring at eight locations in Tigray took place between 2013 and 2016. The impact of different techniques revealed significant impacts on groundwater levels with a converted borrow pit (figure 5) for instance showing an increase of 1.2 to 2 meter in groundwater levels during the dry period (November – March) between 2013 to 2016.

Figure 6 Examples how roads function as embankments in polders in Bangladesh. Both serving as embankment and tool to control water levels withgated culverts.

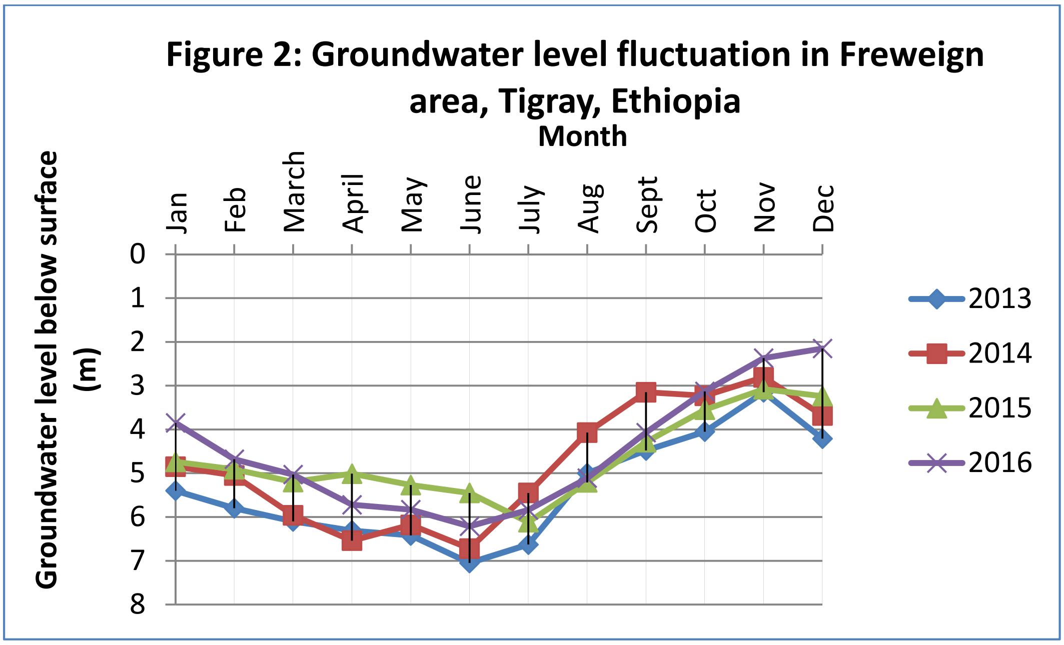

Figure 7 Groundwater level fluctuation

Note: Groundwater fluctuation in Freweign area, Tigray, Ethiopia. The well is located at downstream of a (percolation pond). The borrow pit was converted into a pond on July 2014. Monitoring was done for the whole period 2013 to 2016

Higher yields and improved incomes

All these effects translate in higher yields and improved farmer incomes. Monitoring the effects of road water harvesting on 8 plots in Amhara and Tigray Regions in Ethiopia helped to assess the effect on crop yields. Wheat increased by 22%/186kg per ha, barley increased by 8%/ 75kg per ha, teff increased by 30%/145kg per ha and maize increased 81%/75 kg per ha. On average between these four crops, an increase of 35.5% was observed. This goes in line with previous studies in Ethiopia, which show a 57% increase on yield of teff by using supplemental irrigation from water harvesting ponds and improved nutrient applications (Dile, et al., 2016). In addition, a meta-analysis compiling 217 studies in East Africa revealed that water harvesting increases crop yields with on average 78% (Bouma, Seema, & Lasage, 2016).

Apart from the effect on rain-fed agriculture and irrigation, (either supplemental irrigation in case of a dry-spell within the rainy season, or for irrigation of a second crop during the dry season), a second important use is livestock watering. This is critical in case of drought, during which roadside ponds and converted borrow pits might be the only source of water for livestock in a certain area. The benefits of road water harvesting on livestock are three-fold. First, the road water harvesting ponds provide an important source of stock water. According to Nissen-Petersen (2006) a cow consumes on average 20 litres a day, and given that from 1 km of road surface water 1,920 m^3 of water can be harvested, the potential for livestock could mean sufficient drinking water for 185 cows. Moreover, the availability of water in roadside ponds will shorten the distance livestock needs to move to access water. A second benefit is the increase in quantity and quality of grass. Water from the road is in many cases spread over pasture land. Livestock will benefit from the nutritious grass growing nearby roads. Finally, livestock often feeds on crops residues. Since crops grow better when benefiting from supplemental irrigation (including water from the road), these areas will have more fodder and therefore healthier livestock (Todd-Brown, et al., 2014). A third important function is that of emergency water supply when all other sources dry up.

3. Comparing the costs and benefits of 'roads for water' with conventional resilience approaches

Table 6 adds up the different resilience dividends discussed in section 2.1 to 2.3 The cumulative dividend of the roads for water approach to resilience, as implemented in Ethiopia, is USD 16,879 per km. This compares favourably with the investments of USD 1,800 per kilometre: a nearly ten-fold return is created in the first year. It comes as no surprise that the program has spread fast in the different regions in Ethiopia.

The measures implemented in Tigray and Amhara consist of simple earthworks based interventions – flood water spreaders, road side water ponds and infiltration trenches with no engineering required. It is a minimum but cost-effective package. One may add other measures that will require a redesign of the road, for instance using non-vented road drifts as sand dams; reconsidering the number and locations of road culverts; changing the alignment of the road to optimize run-off capture and routing to productive areas or using road embankments for water storage. These will come with their own costs and benefits and these may be calculated. Indication so far are that such measures equally attractive. Some road for water measures may even be cost saving. An example of such are the use of non-vented drifts (dry river bed road crossings without culverts that help stabilize the river bed and build up sand-water storage upstream of them) or the use of low embankment roads of flood plain areas to have controlled flooding – bringing a big saving in earthwork costs (MRWA Waterways Section and BG&E Pty LTD 2006).

Table 5 Comparing the costs and benefits from a conventional and roads for water resilience approach per 10 kilometre of road

			Roads for Water Approach	Conventional Resilient Roads Approach
Costs		Paved roads	USD 1800	USD 45000[11]
		Unpaved roads	USD 1800	USD 31200
Resilience Dividend				
1	Reduced damage	Reduced cost of road maintenance - Unpaved Paved Periodic - paved Periodic - Unpaved	 USD 1,100 USD 2,200 USD 3,400 USD 1,870	Comparable
		Reduced damage due to erosion	USD 2,675	Negative: considerably more flooding than in base

[11] This figure comes from (Cervigni, Losos, Chinowsky, & Nuemann, 2016) and is based on the estimated prices for new planned investments of 796km multi-country roads under the Programme for Infrastructure and Development (PIDA).

				situation
		Reduced damage due to flooding	USD 1,762	Negative: considerably more flooding than in base situation
		Reduced damage due to sedimentation	USD 180	
2	Unlocking the economic potential	Less down time of roads Reduced impact from climate Change	USD 3,800 USD 550	Comparable Comparable
3	Co-benefits	Beneficial use of water harvested from roads	USD 4,500	0

The cost and benefits of the investment in roads for water resilience measures may also be contrasted with a more conventional approach to resilient roads, as described for instance by Cervigni et al., (2016) and NDF (2014). Whereas in the roads for water approach the environment around the road is managed and the road is made part of the landscape – even using roads as a beneficial instrument for water management, in the conventional resilience approach design specification of road infrastructure itself are adjusted so as to make the road better able to withstand adverse weather effects: wider paved shoulders, stronger subgrades, increasing the gravel wearing thickness using and improved crushed aggregate, so that there is less infiltration into the subgrade layers. To deal with more intense rainfalls, culverts need to be adapted so that they can handle larger volumes of water. A study by the Ethiopian Road Authority (ERA, 2013) for instance suggested that culverts should increase in size by 20% between 2030 and 2090. The cost of this conventional approach to road resiliience is high: from USD 31,000 to USD 45,000 per kilometer. In case of unpaved roads the costs may be prohibitive.

Another suggestion that is being made in the same context is to upgrade unpaved roads to paved roads. This comes at a cost of USD 395,000 per kiometre – with 90% of roads in SSA being unpaved this at best can be implemented in a few selected locations.

The conventional approach to road resilience is considerably more expensive – making particularly for unpaved roads the suggested modification unaffordable. In addition to the cost argument there are two other main points. First is that the conventional approach to resilience will accelerate the vulnerability of the surrounding area, in particular causing more flooding and erosion due to increased uncontrolled cross drainage. Seconly, the conventional approach does not create co-benefits in terms of improved water use. In essence, the conventional approach to road infrastructure resilience missed out on two resilience dividends – the reduced cost of damage to the environment and the co-benefits of beneficial water management and water harvesting.

This comparison also reflects on the definition of resilience and the priorities therein. In the definition of Rodin (2014) the emphasis was on the capacity to restore after crisis. Tanner et al made the point of multiple benefits – in addition to reducing the effects of possible risks, the more secure and multifunctional systems and infrastructure that unlock economic potential and create multiple benefits – as in the case of roads for water capitalizing on the often forgotten opportunities of water management with road infrastructure. This begs the question: how much crisis do we need in resilience? Do we need to reduce the risk of major episodic disaster or can we also prioritize the every-year damage and wear and tear? Should climate change be the only driver to advocate for resilience or should we look at a framework that takes into account all major and minor risks and system imperfections? We argue for the latter option to be considered seriously in the resilience debate and focus on making existing systems stronger and with a wider remit, not primarily related to disaster response.

Figure 8 Diverse techniques to improve road water management to transform landscapes and livelihoods

4. Conclusion

In Sub Saharan Africa road density is still the lowest in the world on almost all parameters. The total length of classified roads[12] in Sub Saharan Africa is 1,052,203 kilometre – to which 492,109 kilometre of unclassified should be added. The classified resp. total road network density stands at 109 resp. 149 kilometer per 1000 km2 in SSA; or 2.5 resp. 3.4 per 1000 persons or 152 kilometers per 1000 vehicles. Compare this to a global average road density of 944 km/ per 1000 km2 and it is obvious that there is a large unfulfilled transport need (Foster and Briceño-Garmendia 2010). In Ethiopia - the focus of this paper - the figures are even lower: 21 resp 46 km per 1000 km2 or 0.3 resp 0.6 kilometer per 1000 persons; or 82 kilometer per 1000 vehicles. By all estimates road construction in SSA will be substantial over the next decades. By 2050, estimates say that there will be 2,883,905 million roads: 15% paved, 72% unpaved, 13% unknown (Cervigni et al. 2016).

This increase in new road construction and upgrading of the road networks in SSA and elsewhere presents considerable opportunities. The first opportunity is that the development of new roads creates many new chances to better manage water resources with the roads and reverse landscape degradation (as is common practice) and instead aid the improvement of landscapes. Transect surveys have indicated that in 10 kilometre of road there are 8-25 flashpoints, where something positive can happen but at present a problem has occurred. The second opportunity is that there is a need to come

[12] Excluding 190,311 kilometres of urban roads.

to a different approach to road development and road rehabilitation, i.e. one that reduces the costs of maintenance and the risk of road failure: at present 39% of the roads in the network in SSA is classified as 'poor' – in other words in need of rehabilitation. The challenge of maintenance is only going to increase as the road network expands and as the effect of climate change is increasingly felt (see section 2.1).

Hence we argue for the systematic use of beneficial road water management. We argue for a new approach to where beneficial road water management is part and parcel of the design, development and maintenance of roads. In this paper we have given the economic argument using monitoring data from the Ethiopia 'Roads for Water' program and from other sources. We have argued that this approach is preferable over a conventional and more narrow resilience approach where the emphasis is on making the road bodies itself stronger and more robust through a range of measures such as large cross drainage, higher and stronger embankments and different subgrades. We argue that such a conventional approach to resilient roads may preserve the road in times of heavier weather, but will do far more damage to the surrounding landscape. Larger cross drainage and higher and stronger road embankments will mean more uncontrolled flooding, more erosion, sedimentation and water logging triggered by road infrastructure. Moreover some of the measures may not be effective – for instance the heavier gravelling of unpaved roads may not be sufficient to climate-proof them without proper measures that drain water from the surface of the unpaved road, preferably for beneficial roadside use.

Many of the proposed roads for water measures moreover come at low additional costs. Some may even constitute a cost saving over conventional road building practices. Different measures to divert road drainage to storage ponds or infiltration trenches or spread water from culverts come at a modest cost compared to the total investment. The program in Ethiopia suggested that USD 1800 per kilometre is sufficient to undertake such measures. This compares favourable with annual maintenance expenditures per kilometre of 1,100 per year on rural roads in SSA and a periodic maintenance of USD 11,200 inflicted from water. For paved roads maintenance expenditures per kilometre per year are USD 2,200 and periodic maintenance – every 6 years due to water 19,200.

Some roads for water measures can in fact make road construction cheaper rather than more costly. A first example is the reuse of borrow pits for permanent water storage rather than backfilling them (often done with low quality soil material). This is a considerable cost saving measure but creates a local water resource almost for free, especially when design criteria are followed (Steenbergen, 2017). Another example concerns the building roads in flood prone areas with lower embankments and equipping them with controlled overflow structures rather than going for high embankments. This reduce costs enormously and prevents that roads wash out in unpredictable locations. A third illustration is the use of non-vented drifts as road crossings. These come at the same costs as vented drifts but prevent the scouring of rivers and encourage the build-up of sand-water storage immediately upstream of them – combining the function of a road crossing with that of a sand dam (Neal, 2012).

Resilience challenges, especially in rural areas, require local resource based solutions that are compatible with local objectives and needs. In the case of Roads for Water, this means that the engineers and technicians who will design the roads, the contractors and labourers who will construct them, the villagers who maintain them and use them must all be direct beneficiaries.

We hence argue for the systematic introduction of the Roads for Water concept in infrastructure programs, adjusting the design criteria, the budgeting systems and the maintenance arrangements. We argue for a close cooperation between road authorities and those responsible for agricultural development, water resources management, disaster risk reduction and local government in general. Roads have much to offer in terms of local development and better water management as part of systems approach to resilience is one prime manifestation of them.

Colophon

This report has been prepared by: Frank van Steenbergen, Kebede Manjur, Nicholas Hawkins, Marta Agujetas Perez, Kifle Woldearegay, Taye Alemayehu, Nathanial Matthews and Jesper Hornberg.

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Bibliography

ADB. (2011). *Guidlines for Climate Proofing Investment in the Trasport Sector.* Asian Development Bank. Asian Development bank.

Addisu, S. (2011). *The Impact of Road Construction on Physical Land Degradation:The case of two selected road projects in Central Highlands of Ethiopia.* Saarbrucken, Germany: LAP LAMBERT Academic Publishing Gmbh & Co. KG.

AFDB. (2014). *Study on Road Infrastructure Costs: Analysis of Unit Costs and Cost Overruns of Road Infrastructure Projects in Africa .* African Development Bank, Statistics Department. African Development Bank Group.

Africon. (2008). *Unit Costs of Infrastructure Projects in Sub-saharan Africa.* AICD. World Bank.

ARC. (2016). *The cost of drought in Africa.* African Risk Capacity.

Ayele, G. K., Gesses, A. A., Addisie, M. B., Tilahun, S. A., Tenessa, D. B., Langendoen, E. J., et al. (2015). The Economic Cost of Upland and Gully Erosion on Subsistence Agriculture for a Watershed in the Ethiopian Highlands. *African Journal of Agricultural and Resource Economics , 10* (4), 265-278.

Bouma, J., Seema, S., & Lasage, J. (2016). Assessing the returns to water harvesting: A meta-analysis. *Agricultural Water Management* , 163:100-109.

Bryan, R. B., & Schnabel, S. (1994). Estimation of Sedimentation Rates in the Chemeron Resavoir . *Advances in Geoecology , 42*, 231-248.

Carlowicz, M. (1996). Natural Hazards Need Not Lead to Natural Disasters . *EOS , 77*, 149-153.

Cervigni, R., Losos, A., Chinowsky, P., & Nuemann, J. E. (2016). *Enhancing the Climate Resilience of Africa's Infrastructure: The Roads and Bridges Sector.* INternational Bank for Reconstruction and Devlopment, Africa Development Forum Series. Washington: World Bank.

Chinowsky, P., & Arndt, C. (2012). Climate Change and Roads: A dynamic stressor-response model. *Review of Climate and Roads: A Dynamic stressor-Response Model , 16* (3), 10.1111/j.1467-9361.2012.00673.x.

Conway, G. (2009). *he Science of Climate Change in Africa: Impacts and Adaptation.* Imperial College London, International Development, London.

Demenge, J., Alba, R., Welle, K., Manjur, K., Addisu, A., Mehta , L., et al. (2016). Multifunctional Roads: The Potential Effects of Combined Roads and Water Harvesting Infrastructure on Livelihoods and Poverty in Ethiopia. *Journal of Infrastructure , 7* (2).

Desta, L., Carruci, V., Wendem-Agenehu, A., & Abebe, Y. (2005). *Community Based Participatory Watershed Development:A Guidline.* Annex, Ministry of Agriculture and Rural Development.

Dile, Y. T., Karlsberg, L., Temesgen, M., & Rockström, J. (2013). The role of water harvesting to achieve sustainable agricultural intensification and resilience against water related shocks in sub-Saharan Africa. *Agirculture, Ecosystems & Environment , 181* (1), 69-79.

Dile, Y., Karlber, L., Daggupati, P., Srinivasan, R., Wiberg, D., & Rockstrom, J. (2016). Assessing the Implications of Water Harvesting Intensification on upstream-downstream Ecosystem Services:A case study in the Lake Tana basin. *Science of the Total Environment , 542*, 22-35.

Dulac, J. (2013). *Global land transport infrastructure requirements: Estimating road and railway infrastructure capacity and costs to 2050.* International Energy Agency. France.

El-Swaify , S. A., & Hurni, H. (1996). Transboundary Effects of Soil Erosion and Conservation in the Nile Basin. *Land Husbandry , 1* (1), 7-21.

ERA. (2013). *Drainage Design Manual.* Ethiopian Roads Authority. Addis Ababa: Etiopian Road Authority.

Falkenmark, M. (2017). Water and human livelihood resilience: a regional to global perspective. *International Journal of Water Resources Development* , 33:2, 181-197.

FAO. (2017). *Ethiopia:drought response plan and priotities in 2017.* Food and Agriculture organisation.

FAO. (2017). *GIEWS FPMA Tools:monitoring and analysis of food prices*. Retrieved 2017 from Food and Agriculture Organisation: http://www.fao.org/giews/food-prices/tool/public/index.html#/dataset/domestic?country=ETH

FEWS. (2017, April). *Ethiopia Food Security Outlook Update.* Retrieved June 2, 2017 from Famine Early Warning Systems Network: http://reliefweb.int/sites/reliefweb.int/files/resources/ET_FSOU_2017_04_Final.pdf

Forman, R. T., & Alexander, L. E. (1998). Roads and their Major Ecological Effects. *Annual Review of Ecology and Systematics , 29*, 207-231.

Geddes, R. (2016). *Economic Growth Through Effective Road Asset Management.* AFCAP. Thame: Africa Community Acess Partnetship.

Grafton, R., Williams, J., & Jiang, Q. (2017). Possible pathways and tensions in the food and water nexus. *Earth's Future* .

Grum, B. (2017). *Effect of Water Harvesting Techniques on Hydrological Processes and Sediment Yield in Northern Ethiopia.* Wageningen University, Socio-Economic and Natural Sciences of the Environment. Wageningen: Wageningen University.

Grum, B., Woldearegay, K., Steenbergen, F. V., Puertas, D. G.-L., Beusekom, M. V., & Agujetas, M. (2016). *Reconnaisance Report: Potentials of Water Harvesting from Road Catchments: The Case of Freweign-Hawzien-Abreha Weatsbeha Route, Tigray, Northern Ethiopia.* Mekelle University, Mekelle.

Gwilliam, K., Bofinger, H., Bullock, R., Carruthers, R., Kumar, A., Mundy, M., et al. (2011). *Africa's Transport Infrastructure: Maintreaming Maintenance and Management.* World Bank. The World Bank.

Hearn, G. (2014). *Promoting Sustainable Rural Access and Developing a Risk Based Vulnerability Assessment for Rural Communities in the Changing Climate of Sub Saharan Africa.* Hearn Geoserve. Crown Agents.

Hurni, K., Zeleke, G., Tegegne, B., Kassawmar , T., Teferi, E., Moges, A., et al. (2015). *Soil Degradation and Sustainable Land Management in the Rainfed Agricultural Areas of Ethiopia: An Assessment of the Economic Implications.* Report for Economics of Land Degradation Initiative, Water and Land Resource Center, Addis Ababa.

Ibisch, P. L., Hoffmann, M. T., Kreft, S., Pe'er, G., Kati, V., & Biber-Freudenberger, L. (2016). A global map of roadless areas and their conservation status. *Nature* , 1423 - 1427.

IFAD. (2016). *Rural Development report 2016: Fostering Inclusive Rural Transformation.* International Fund for Agriculture and Development. Rome: Quintily.

Initiative, E. (2015). *The value of land: Prosperous lands and positive rewards through sustainable land management.*

Jägermeyr, J., Gerten, D., Schapoff, S., Heinke, J., Lucht, W., & Rockstorm, J. (2016). Intergrated Crop Water Management Might Sustainably Halve the Global Food Gap. *Environmental Science Research Letters , 11* (2).

Kopp, A., Block, R. R., & Limi, A. (2014). *Turning the Right Corner: Ensuring Development through a Low-Carbon Transport Sector.* World Bank, Environment and Sustainable Development. Washington: International Bank for Reconstruction and Development.

Kruskopf, M. (2013). Hydrological Monitoring of the TBIWRDP programme watersheds. *TB WME Completion Siminar.*

Kubbinga, B. (2011). *Road Runoff Harvesting in the Drylands of Sub-Saharan Africa:It's potential for Assisting Smallhoilder Farmers in Coping with Water Scarcity and Climate Change, Based on Case Studies in Eastern Province, Kenya.* Thesis, Free Univesity Amsterdam, Faculty of Earth and Life Sciences.

Liniger, H., Mekdachi, S., Hauert, C., & Gurtner, M. (2011). *Sustainable Land Management in Practice: Guidelines and Best Practices for Sub-saharan Africa.* WOCAT. FAO.

Logar, I., & Van den Bergh, J. C. (2011). *Methods for Assessment of the Cost of Droughts.* Institute of Environmental Science and Technology.

Luce, C. H., & Black, T. A. (1999). Sediment Production from Forest roads in Wester Oregon. *Water Resources Research , 35* (8), 2561-2570.

Luce, C. H., Rieman, B. E., Jason, D. B., Clayton, J. L., King, J. G., & Black, T. A. (2001). Incorporating Aquatic Ecology Into Decisions on Prioritization of Roads Decommessioning. *Water Resource Impact , 3* (3), 8-14.

Makanzu, I., Dewitte, O., Ntombi, M., & Moeyersons, J. (2014). Topographic and road control of Mega-gullies in Kinsasha. *Geomorphology , 217*, 131-139.

Mati, B. M., Muchuri, M. J., Njenga, K., De Vried, F. P., & Merrey, J. D. (2006). *Assessing water availability under pastoral livestock systems in drought-prone Isiolo Distrcit, Kenya.* International Water Management Institute . IWMI.

Megahan, W. F., Wilson, M., & Monsen, B. S. (2001). Sediment Production from Granitic Cutslopes on Forest Roads in Idaho, USA. *Earth Surf. Process. Landforms , 26*, 153-163.

Mekonnen, M., Keesdtra, S., Baartman, J., Ritsema, C., & Melesse, A. (2015). Evaluating sediment storage dams: structural off-site sediment trapping measures in northwest Ethiopia. *Cuadernos de Investigacion Geografica , 1* (44), 7-22.

Moeyersons, J. (1991). Ravine formation on steep slopes: Forward versus regressive erosion. Some case studies from Rwanda. *CATENA , 18*, 309-324.

Morgan, R. (2009). *Soil Erosion and Conservation* (Vol. 3). John Wiley & Sons.

Mosley, L. M. (2014). Drought Impacts on the Water Quality of Freshwater Systems: Review and Integration. *Earth-Science reviews* , 203-214.

Mutekwa, T., & Kusangaya, S. (2006). Contribution of rainwater harveting technologies to rural livelihoods in Zimbabwe: the Case of Ngundu ward in Chivi District. *Water S.S , 32* (3), 437-444.

Mutinga, J. K., & Zhongbo, S. (2011). Impacts of agricultural intensification through up-scaling of suitable rainwater harvesting technologies in the upper Ewase Ngiro North basin, Kenya. *Hydrology if Earth System Sciences Discussions , 8* (2).

NCDFR. (2007, December). *North Carolina Forest Practice Guidlines Related to Water Quality*. From North Carolina Division of Forest Resources: http://ncforestry.info/ncdfr/forest_practices_guidelines_related_to_water_quality/

NDF. (2014). *Cambodia Rural Roads Invesment Project: Results from Climate Change Adaptation.* Nordic Development Fund, NDF. NDF.

Neal, I. (2012). The potential of sand dam road crossings. *Dams and Reservoirs, 22* , 129–143.

Newcombe, C. P., & Macdonald, D. D. (1991). The Effects of suspended Sediments on Aquatic Ecosystems. *North American Journal on Fisheries Management , 11* (1), 72-82.

Nigigi, S. N. (2003). What is the limit of up-scaling rainwater harvesting in a river basin? *Physics and Chemistry of the Earth , 28* (20-27), 943-956.

Nissen-Petersen, E. (2006). *Water from Roads: A handbook for techniciand and farmers on harvesting rainwater from roads.* Danish International Development Assistance . ASAL Consultants ltd.

Nkonya, E. M., Anderson, W., Kato, E., Koo, J., Mirzabaev, A., von Braun, J., et al. (2016). Chapter 6. In A. M. Ephraim Nkonya, *Global cost of land degradation. In Economics of land degradation and improvement- A global assessment for sustainable development* (pp. 117 - 165).

NMA. (2007). *Climate change national adaptation programme of action (Napa) of Ethiopia.* Ministry of Water Resources, National Meteorological Agency. Addis Ababa: UNDP.

Oruonye, E. D. (2015). An Assessment of the Impact of Road Construction on Land Use Pattern in Urban Centres in Nigeria, A Case Study of Jalingo LGA, Taraba State Nigeria . *Mediterranean Journal of Social Sciences , 5* (10), Doi:10.5901/mjss.2014.v5n10p82 .

Puertas, D. G., Woldearegay, K., Mehta, L., Beusekom, M., Agujetas, M., & Steenbergen, F. V. (2014). Roads for Water:The Unused Potential. *Waterlines , 33* (2), DOI: 10.3362/1756-3488.2014.013.

Roberts, P., KC, S., & Rastogi, C. (2006). *Rural Access Index : A Key Development Indicator.* World Bank, Washington, DC: Transport paper series; no. TP-10.

Rodin, J. (2014). *The resilience dividend: being strong in a world where things go wrong.* New York: PublicAffairs.

Senay, G. B., & Verdin, J. P. (2004). Developing index maps of water-harvesting potential in Africa. *Applied Engineering in Agriculture , 20*, 789-799.

Shah, T. (2010). *Taming the anarchy: groundwater governance in South Asia.* Resources of the Future.

Steenbergen, F. v. (2017). *Road-side borrow pits as ponds for off-season small-scale irrigation. .* AFHRINET. Hamburg: Hamburg University of Applied Sciences.

Symeonakis, E., & Drake, N. (2004). Monitoring Desertification and Land Degradation over Sub-saharan Africa. *International Journal of Remote Sensing , 24* (3), 573-592.

Tadesse, A. Y. (2015). Flash Floods in Dire Dawa, Ethiopia. *Journal of Social Sciences and Humanities , 1* (4), 400-414.

Tamene, L., Park, S. J., Dikau, R., & Vlek, P. L. (2006). Reservoir siltation in the semi-arid highlands of northern Ethiopia: sediment yield–catchment area relationship and a semi-quantitative approach for predicting sediment yield. *Earth Surface Process and Landforms , 31* (11), 1364-1383.

Tanner, T., Rentschler, J., Surminski, S., M. T., M. R., Wilkinson, E., et al. (2015). *Unlocking the 'triple dividend' of resilience.* Washington, D.C. and London: GFDRR, World Bank and Overseas Development Institute.

Taylor, T., Markandya, A., Droogers, P., & Rugumayo, A. (2014). *Economic assessment of the impacts of Climate Change in Uganda.* Climate & Change Development Network, Ministry of Water and Environment .

Todd-Brown, K. E., Randerson, J. T., Hopkins, F., Arora, V., Hajima, T., Jones, C., et al. (2014). Changes in soil organic carbon storage predicted by Earth System models during 21st century. *Biogeosciences , 11* (8), 2341-2356.

Torbjorn, A., & Bharat P, B. (2012). Contribution of Rural Road Acess to- and Participation in Markets: Theory and Results from Northern Ethiopia. *Journal of Transportation Technologies , 2*, 165-174.

UNOCHA. (2017). *Horn of Africa: A Call for Action*. Retrieved June 5, 2017 from Relief Web: http://reliefweb.int/sites/reliefweb.int/files/resources/HOA_CALL_FOR_ACTION_Leaflet_Feb2017_1.pdf

Wemple, B. C. (2013). *Assesing the Effects of Unpaved Roads on Lake Champlain Water Quality.* New England interstate Water Pollution Control Commision, Lake Champlain Basin Program.

Wilhite, D. A. (2000). Drought:A global Assessment. *1* (1), 3-18.

WMO;GWP. (2017). *Benefits of Action and Cost of Inaction: Drought Mitigation and Preparedness - A literature Review.* World Meteorological Organization & Global Water Partnership, Integrated Drought Management Programme (IDMP). Sweden: WMO.

Wolancho, K. W. (2012). Watershed Management: An Option to Sustain Dam and Reservoir Function in Ethiopia. *Evironmental Science and Technology , 5* (5), 262.

Woldearegay, K., Puertas, D. G.-L., Steenbergen, F. V., Beusekom, M. V., & Agujetas, M. (2014, May). *Reconnaissance Report for Water harvesting from roads in Tigray, Northern Ethiopia: Practices, Opportunities and Design Considerations.* Retrieved May 22, 2017 from Road for Water: http://roadsforwater.org/wp-content/uploads/2013/05/Report_Road_and_Water_Tigray_smll.pdf

Woldearegay, K., Steenbergen, F. V., Agujetas, M., Grum, B., & Beusekom, M. V. (2015). Water Harvesting from Roads: Climate Resilience in Tigray, Ethiopia. *IRF Europe & Central Asia Regional Congress.* Istanbul, Turkey: Research Gate.

World Bank. (2016). *Poverty and Shared Prosperity 2016: Taking on Inequality.* Washington: World Bank.