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An Interdisciplinary Investigation into the Linkages between Transport, the Environment, Climate Change, Hydrology, Agriculture and Food Security in the rural Letaba District, Limpopo Province, South Africa/

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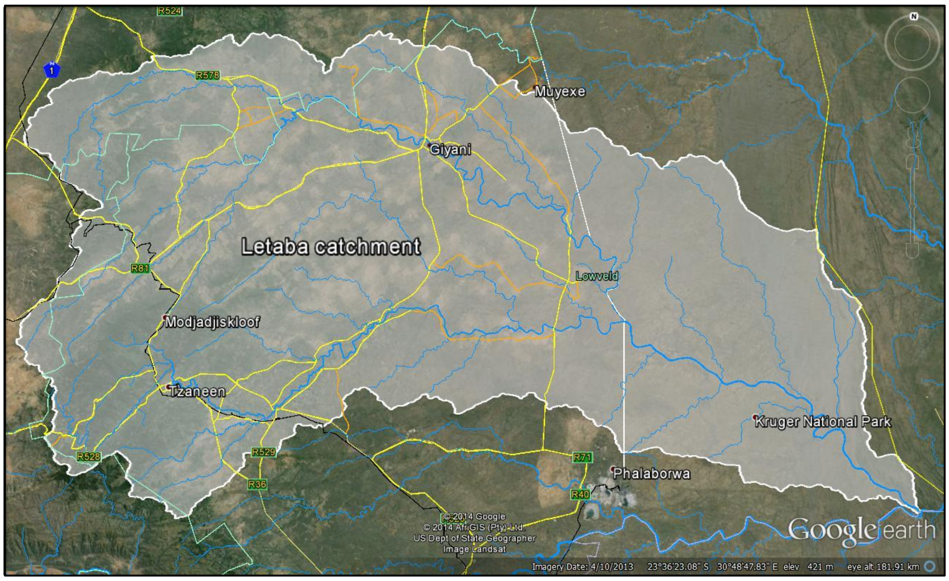

14 BRITISH EXPERTISE INTERNATIONAL AWARDS WINNER

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Report summary

This report chronicles an interdisciplinary investigation to determine the linkages between transportation, the environment, climate change, hydrology, agriculture and food security. The report starts with an overview of the study purpose and approach. This is followed by a detailed description of the Letaba district, a rural district in South Africa which forms the study area in this research. Specific attention is paid to the state of transportation in the area, as well as proposed economic developments. Next, the link between climate change and transportation is investigated, followed by a similar investigation into the linkages between transportation and the environment (including links to hydrology, agricultural potential and food security). A scenario based transport impact assessment is done for the study area. Based on the results from this assessment, certain generalised findings are concluded. The most notable finding is confirmation of the notion that, whilst proposed regional developments might be beneficial economically or socially, they could unwittingly trigger a number of negative environmental impacts. It is also found that an environmental impact assessment should not simply stop at the direct environmental impacts, but should consider the indirect and compound impacts of a proposed development as well. Disregard of indirect impacts can grossly underestimate the full impact of a proposed development. The study concludes that transportation, the environment, climate change and a region's hydrology, its agricultural productivity and food security all form an interrelated system that needs to be balanced in order to achieve true sustainability.

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Abstract/

The purpose of the study documented in this report was to determine the linkages between transportation, the environment, climate change, hydrology, agriculture and food security. Based on these links, the (direct and indirect) consequences of planned transportation development in the Letaba district of South Africa were investigated. The Letaba district is a rural, impoverished area in South Africa, which is earmarked for future development and upliftment. Determining the reciprocal relationship between climate change and transportation, first in a theoretical sense and then as it pertains to the Letaba district, specifically, formed a substantial component of the study. Another focal point was the establishment of theoretical links between transportation and the environment. Based on these links, transport development impact assessments were done for various potential regional development scenarios, considering the influence of expected climate change in the area. It was found that agricultural productivity can be severely affected by transportation development in an area similar to the Letaba district. This is largely due to the multitude of hydrological impacts caused by transportation development. The main negative impact of planned transportation expansion in the region will, however, be on the average health of the local community. It was also confirmed that gravel roads exacerbate certain adverse transport related impacts. The most profound conclusion is the extent to which indirect, often hidden, impacts contribute to overall impacts. These secondary and tertiary relationships are often omitted from impact assessments, whilst they should be regarded as focal points for mitigation initiatives instead.

1. Introduction

1.1 Background

Person and freight transportation services are both fundamental tools in the provision of, and improvement in, accessibility of rural areas. However, despite the positive impact transportation can have on a region, there are always consequences (be it intended or unintended) to take into account. In order to provide **sustainable** access to rural areas, transport initiatives should be planned cognisant of the overall impacts on the area.

Current planned development of the Letaba district in the Limpopo Province of South Africa is intended to expose the impoverished rural community to new social and economic opportunities. However, these developments will initialise the expansion of transportation activities in the area. As mentioned, to ensure the sustainability of new developments, the full extent of the consequences of such endeavours needs to be established, understood and managed.

1.2 Research objective

It is the objective of this study to determine the linkages between transportation, the environment, climate change, hydrology, agriculture and food security. Based on these links, the direct and indirect consequences of planned transportation development in the Letaba district of South Africa are investigated.

1.3 Research methodology

This study is mainly a desk based research study, where both published and grey literature are consulted. Further to this, a data collection exercise is undertaken, to supplement the literature and calibrate findings for the study area specifically. The research methodology is summed up in Figure 1.1. Initially, a literature review on the environmental impacts of transportation is done, in conjunction with a data collection exercise on current transport activity in the Letaba region. This is supplemented by an investigation into the current (transportation) development plans for the region. Also, a study on the linkages between climate change and transportation (both the impacts of climate change on transportation and the impacts generated by transport's influence on climate change) is done. During the literature based study, the links between transportation impacts and hydrology are identified. Further to this, a literature based derivation of the impacts of altered water and soil quality on agricultural productivity, and the resultant crop types that can be successfully grown, is done.

The outputs and insights gained from this literature review are used in the formulation of a transport impact assessment model for the Letaba region, as well as in the formulation of climate change dependent regional development scenarios. The regional development scenario analysis is performed twice: once under the assumption that present-day weather patterns hold in the future and once under the assumption that climate change projections for the Letaba region for 2050 (as published by the Council for Scientific and Industrial Research (CSIR) from South Africa) materialise. This enables an analysis of the impact that climate change is expected to have on the overall environmental burden due to transport in the region.

Study results are analysed and interpreted on two scales: first, specifically related to the Letaba region and, secondly, the potential for generalisation of the findings are investigated. To account for uncertainty, a sensitivity analysis forms part of the modelling phase of the study.

1.4 Research scope

Although a generalised literature review is undertaken, the scope of the quantified analysis in this study includes only the localised impacts generated by physical transportation activities (propulsion), as well as the localised impacts from the provision of the infrastructure, equipment (vehicles) and fuels required to enable transportation activities in the study area. The study is limited to the estimation of environmental and social impacts only, and excludes a detailed economic impact analysis. An investigation into the potential impacts of climate change on transportation activities within the region is included within the research scope. Geographically, the study is restricted to part of the Letaba water basin in rural South Africa.

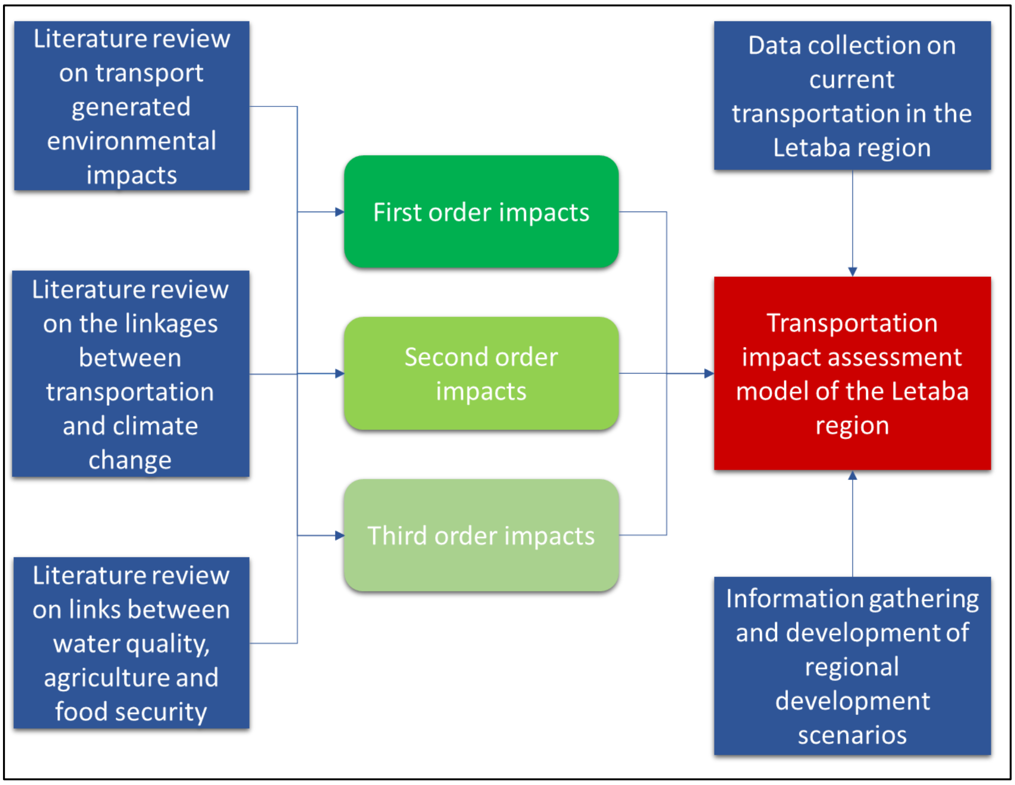


Figure 1.1 Schematic representation of study methodology

1.5 Outline of the report

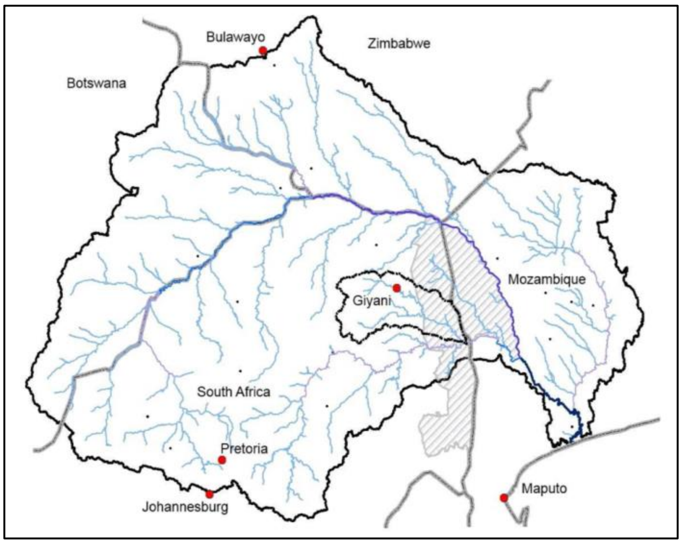
The study area (Letaba basin) is introduced in section 2, where an overview of transport activity and infrastructure in the region is provided. Section 3 explores the development potential of the region. The link between transportation and climate change is established in section 4 while section 5 details the environmental impacts from transportation and distinguishes between the three orders of impacts. The transport impact assessment approach is described in section 6 and the regional development scenarios to be used in this study are introduced. The transport impact assessment results follow in section 7. The report concludes in section 8.

2. The Letaba basin – the status quo

2.1 Overview

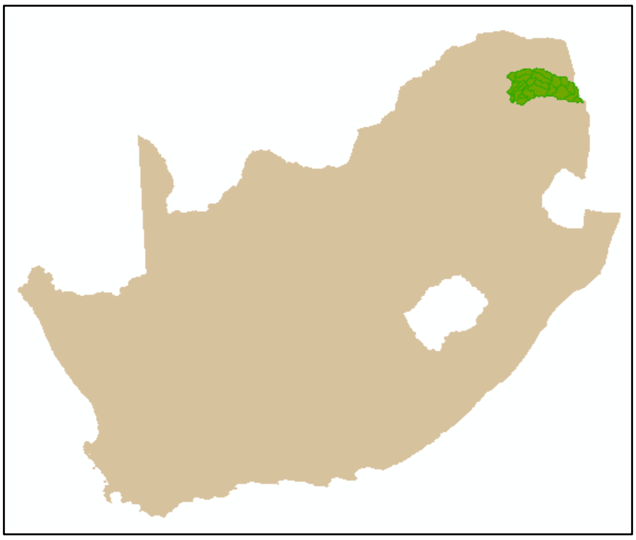
2.1.1 Geographical location

The Letaba water basin catchment forms part of the Limpopo basin (Figure 2.1). Giyani, as well as part of the Kruger National Park (the shaded area), falls within the Letaba basin. Figure 2.2 shows the location of the Letaba catchment within South Africa. The catchment resides in the Limpopo province. Administratively, the basin overlaps mostly with the Mopani district municipal region (with the Greater Giyani, Greater Letaba, Greater Tzaneen and Ba-Phalaborwa municipal areas) and to a lesser extent with the Vhembe district municipality region (specifically parts of the Thulamela and Makhado municipal areas (Figure 2.3). A more detailed view of the subsidiary municipal demarcations in each district is provided in Figure 2.4 and Figure 2.5 for the Mopani and Vhembe districts, respectively.



(Querner & Froebrich, 2014)

Figure 2.1 The Letaba basin (near Giyani) shown as part of the Limpopo basin

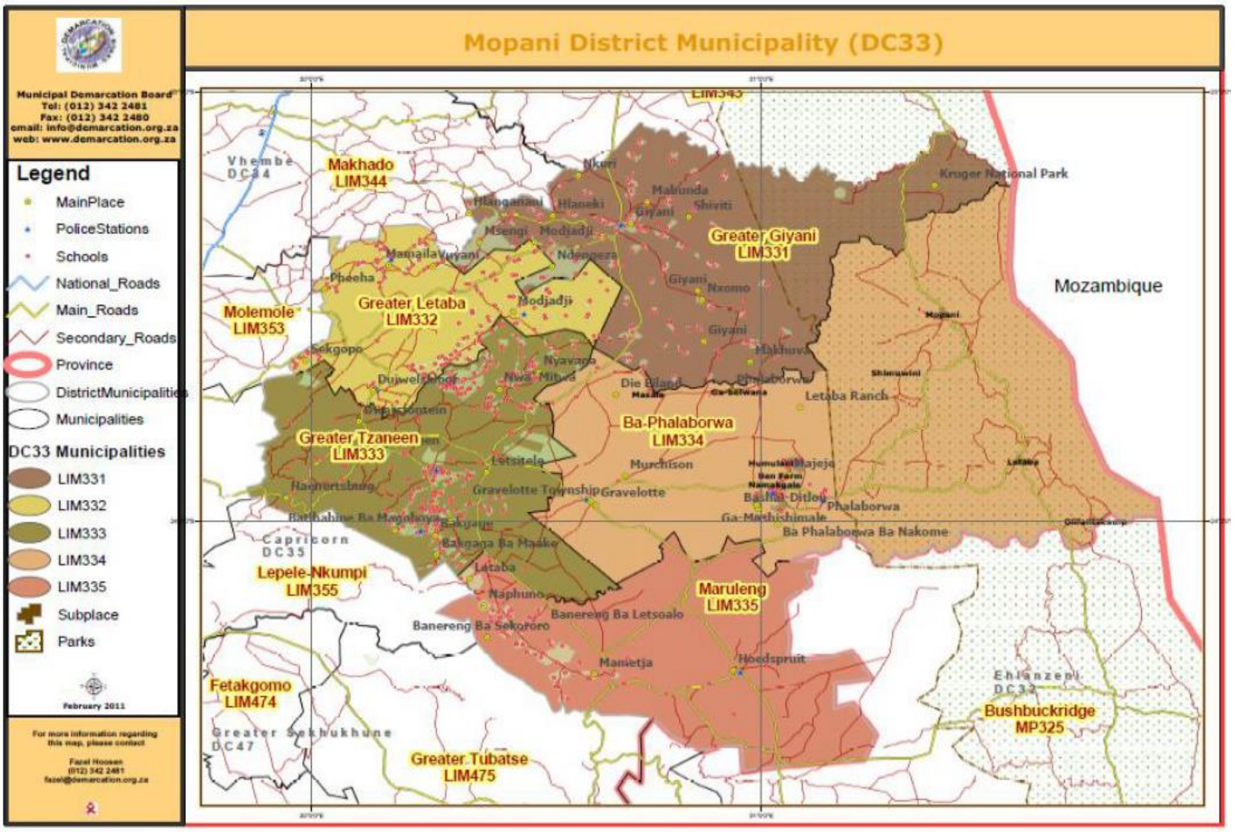


(van Breda, 2014)

Figure 2.2 The location of the Letaba catchment within South Africa

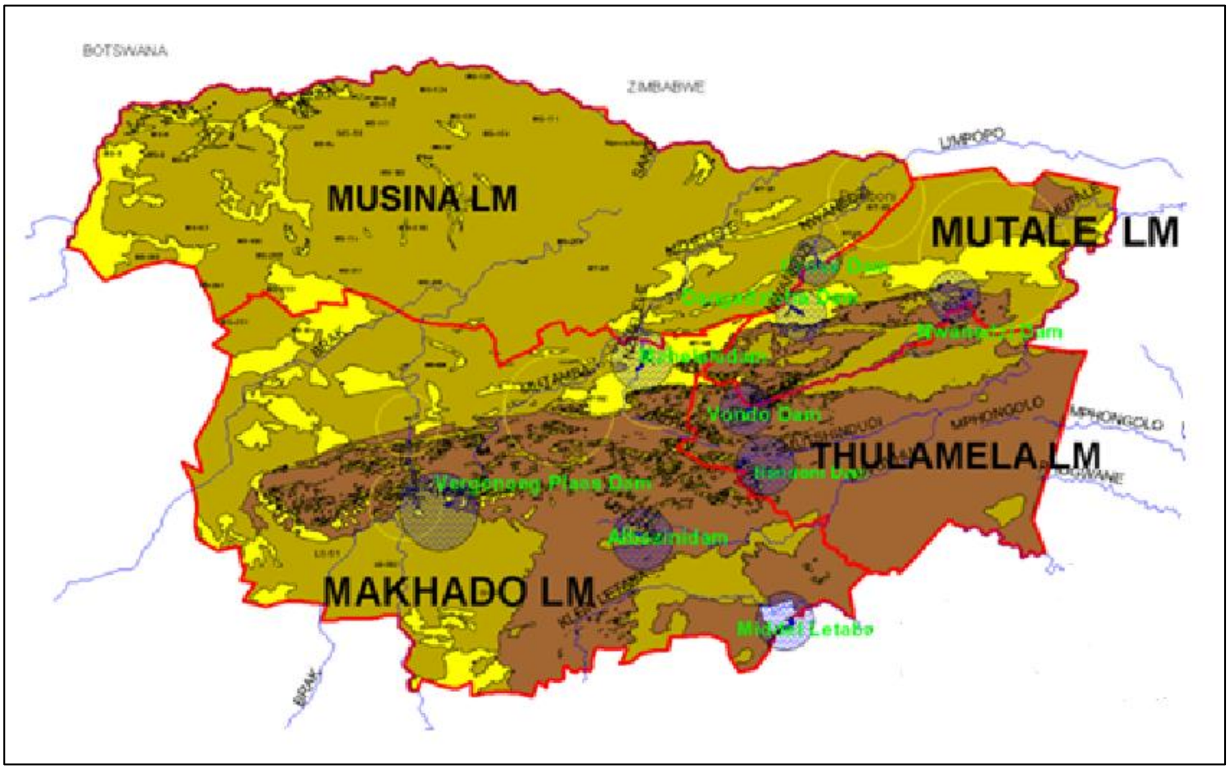
(Limpopo Provincial Government, 2012)

Figure 2.3 District municipalities of the Limpopo province



(Mopani District Municipality, 2013)

Figure 2.4 Mopani district municipality and subsidiary municipalities



(Vhembe District Municipality, 2012)

Figure 2.5 Vhembe district municipality and subsidiary municipalities

2.1.2 Demography

The estimated population statistics for the Mopani district is provided in Table 2.1. Greater Tzaneen is the most populous municipal area. The highest population growth is occurring in the Ba-Phalaborwa municipality, most likely due to the economic development in that area. Apart from the Ba-Phalaborwa municipality, all the other municipalities are constituted of predominantly rural populations. A steady growth in the district population has been observed between 2001 and 2011. This trend is in line with the national and provincial growth trends and also applies to the municipalities within the Vhembe district (Table 2.2).

Table 2.1 Mopani district municipality population estimate comparing census 2001 to census 2011 data

Municipality	Area/ Extent	Population			Households			Pop. Density per hectare		H/H Size		Rural population	Urban population	Farming population
		2001	2011	Growth	2001	2011	Growth	2007	2011	2001	2011			
Greater Giyani	4 171,6 km²	239289	244 218	+2,06%	53292	63548	+19,2%	14	16	5	4	89,5%	10,5%	0
Greater Letaba	1 890,9 km²	220103	212 701	-3,4%	53747	58261	+8,4%		25	5	4	94,3%	5,7%	0
Greater Tzaneen	3 242,6 km²	375586	390 098	+3,9%	97425	108926	+11,8%		24	4	4	82%	10,4%	7,6%
Ba-Phalaborwa	7 461,6 km²	131088	150 635	+14,9%	33572	41115	+22,5%		25	4	4	36,2%	51,0%	12,8%
Maruleng	3 244,3 km²	94382	94 855	+0,5%	23050	24470	+6,2%		16	5	4	88,7%	2,3%	9,0%
DMA		997			611					2				
Mopani/ Total	**20 011,0 km²**	**1 061 445**	**1 092 507**	+2,7%	**261 697**	296320	**+13,2%**		23	**5**	**4**	**81%**	**14%**	**5%**

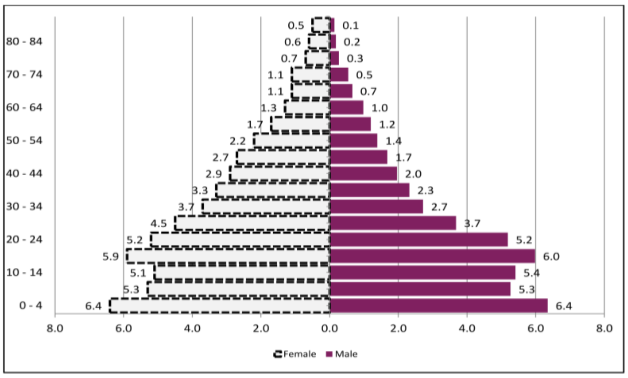
(Mopani District Municipality, 2013)

Table 2.2 Vhembe district municipality population estimates

Population	Year	Musina	Mutale	Thulamela	Makhado	Vhembe	Limpopo	South Africa
	1995	32,795	69,399	532,933	455,479	1,090,606	4,876,898	40,171,605
	2004	42,656	81,234	606,075	515,050	1,245,015	5,466,932	45,857,655

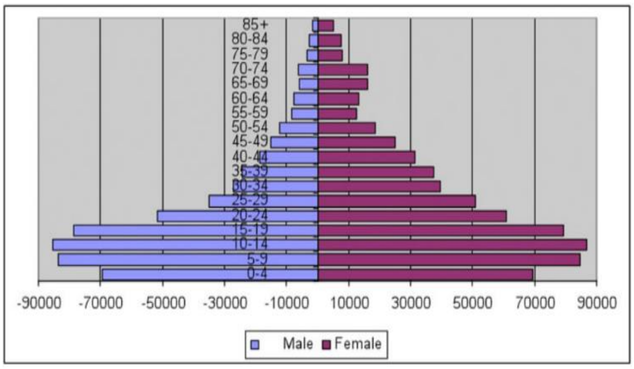
(http://www.vhembe.gov.za/)

The age and distribution profiles of both municipal districts (Mopani - Figure 2.6; Vhembe - Figure 2.7) are very similar. The tendencies revealed are as follows: in almost all local municipalities there are more females than males (with an average ratio of 54:46) (Mopani District Municipality, 2013). This is most significant in Greater Giyani and Greater Letaba municipalities which are primarily rural in nature. The scenario could be attributed to low levels of education and affluence in these municipalities, exacerbated by men seeking jobs elsewhere (Mopani District Municipality, 2013). The other dimension worthwhile to note is that the current highest population number exists in the age category of 10 to 19. These are school-going people who need support for them to be employable in the economic sectors. Unemployment figures are already very high in the region, and with the expected growth in work force, substantial economic development is required for social upliftment.



(Mopani District Municipality, 2013)

Figure 2.6 Mopani district municipality population age and gender distributions



(http://www.vhembe.gov.za/)

Figure 2.7 Vhembe district municipality population age and gender distributions

2.1.3 Regional economy

Limpopo, the province within which Mopani District is located, is the second poorest province in the country. Approximately 77% of the population lives below the poverty income line, and the province also has the lowest human development index score (0,485) in the country (Mopani District Municipality, 2010). Although the number of unemployed people has declined, the percentage of people with no income in Mopani is still higher than the average in the Limpopo Province (Mopani District Municipality, 2010). The majority of people in the district (at least 81%) live in rural areas and the most of these rural residents are poor. Income in rural areas is constrained by the rural economy that is unable to provide people with remunerative jobs or self-employment opportunities. A notable percentage of people in the district have no income (Mopani District Municipality, 2010).

The Capricorn and Mopani districts are seen as the main economic engines of the province, with Polokwane, Phalaborwa and Greater Tzaneen identified as the principal economic centres (Mopani District Municipality, 2010). Economic opportunities in the district are currently highly concentrated around Phalaborwa (and to a lesser extent Tzaneen). Outside of these centres, Mopani contains some of the country’s least developed and poorest communities. In 2006, 11% of Mopani residents lived in a state of absolute poverty (Mopani District Municipality, 2010).

Giyani town is the largest and most densely populated centre in the Greater Giyani Municipality, featuring the most employment opportunities, as well as the best shopping and recreational facilities (www.greatergiyani.gov.za). Key sectors of the local economy are manufacturing, trade, catering, local government, finance, transport, communications and agriculture (Greater Giyani Municipality, 2009). The labour force consists of skilled, semi-skilled and a large percentage of unskilled people. It is the administrative and commercial centre of the Mopani district and also the former capital of Gazankulu (www.greatergiyani.gov.za).

Key natural resources in the Greater Tzaneen municipality are: land (for agricultural development, mining and quarrying, property development and grazing land for domestic and wild animals), rivers, waterfalls and dams (for agricultural irrigation, human consumption and tourism), forests (for sawmills and manufacturing, improvement of biodiversity and biosphere and soil conservation) and nature reserves (for environmental management, improvement of the ecosystem, preservation of indigenous species and animals and tourism) (Greater Tzaneen Municipality, 2012).

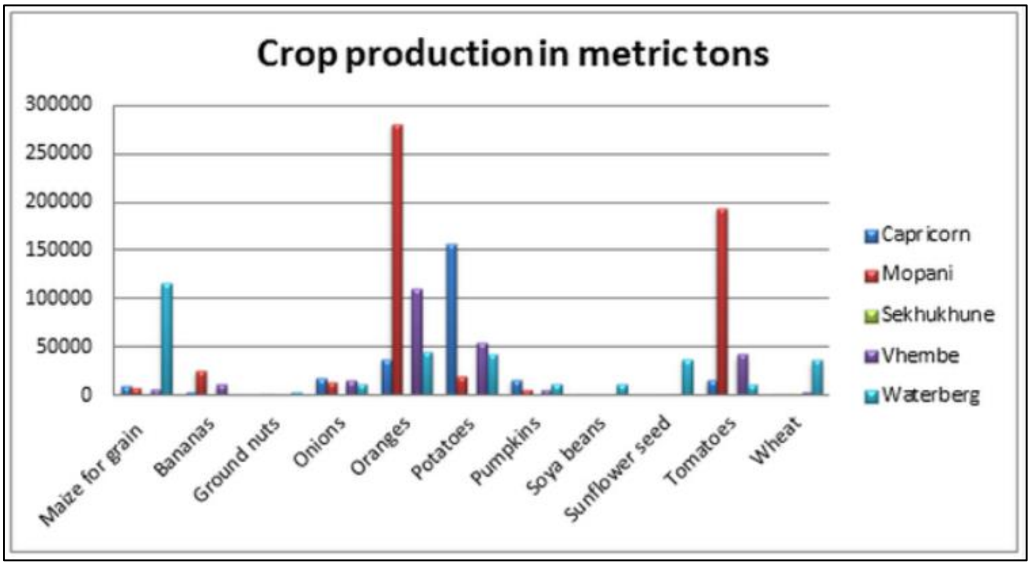
2.1.3.1 Agriculture

Agriculture is a key economic sector in the Limpopo Province. There are two distinct agricultural production systems in the province, small-holder agriculture and large scale commercial farming. Large scale commercial agriculture is characterized by large farms, it is mainly situated on prime agricultural land, it occupies about 70% of the agricultural area and it utilizes advanced production technologies (Querner & Froebrich, 2014). Small-holder agriculture is located mostly in the former homeland areas and covers about 30% of the provincial land surface area. Small-holder agriculture is characterized by a low level of production technology and small land holdings of approximately 1.5 ha per farm. The small-holder sector production is primarily for subsistence with small surpluses, which are marketed. Although irrigated agriculture is of great importance to the Limpopo Province, shortages of water impact on the sector (Querner & Froebrich, 2014). Small-scale farmers have historically been excluded from markets in South Africa. The dominance of large-scale farmers in the South African agricultural commercial sector and the development of centralised procurement and preferred suppliers’ schemes by buyers of fresh produce, such as supermarkets, are some of the factors that contributed strongly to the exclusion of small-scale farmers. However, with political and social changes in the country, as well as the spreading of supermarkets in rural areas, there are new and innovative strategies towards including small-scale farmers into supermarket procurement systems (Querner & Froebrich, 2014).

Limpopo is one of the country's richest agricultural areas. The province accounts for a staggering 45% of the $267 million annual turnover of the Johannesburg Fresh Produce Market (Limpopo Provincial Government, 2012). Subtropical fruit is grown in abundance - mangoes, avocados, papayas, bananas, pineapples and litchis, as well as citrus fruits. The province grows two-thirds of the country's tomatoes and more than a third of its tea. Other crops include potatoes and other vegetables, coffee, nuts, guavas, table grapes, sisal, cotton, sunflowers, maize and tobacco (Figure 2.8). Other agricultural produce in Mopani are red and white meat (Figure 2.9).

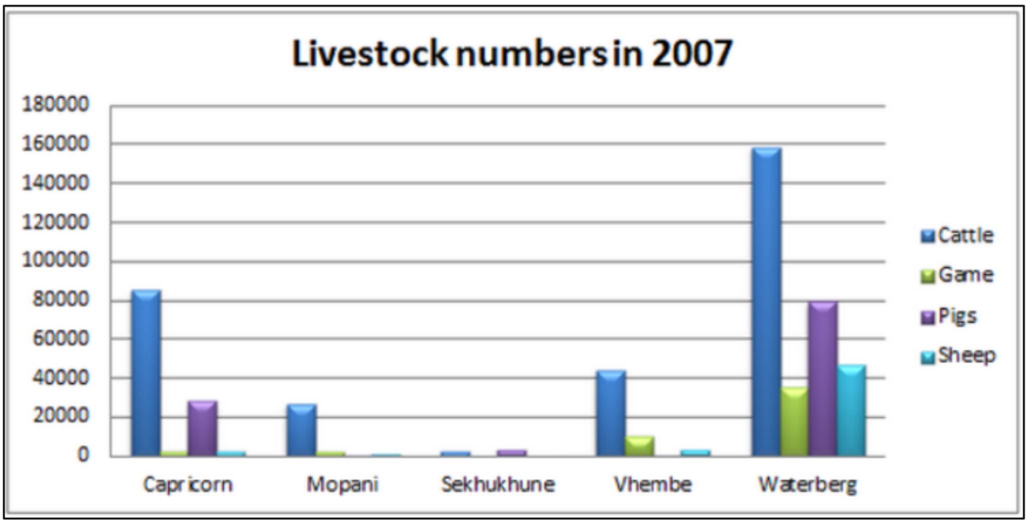
Limpopo's agricultural produce forms a huge portion of the national export. According to the Limpopo Business 2012 publication, the Vhembe District in the far north and the Letaba Valley in the eastern Mopani District are major contributors to the Johannesburg Fresh Produce Market. The produce is distributed nationally predominantly by road and internationally through the ports of Cape Town, Durban and Maputo. In 2011, Transnet indicated that the rail sector is aiming to play a much bigger role in transporting of the agricultural products.

Mopani boasts a large pool of cheap, unskilled labour to work in labour intensive agricultural programmes (Mopani District Municipality, 2010).



(Limpopo Provincial Government, 2012)

Figure 2.8 Agricultural produce in the Limpopo province in 2007



(Limpopo Provincial Government, 2012)

Figure 2.9 Livestock farming in Limpopo in 2007

2.1.3.2 Forestry

Limpopo's timber industry is concentrated in the eastern regions. Forests stretching northwards and eastwards of Tzaneen are a major source of pine and eucalyptus timber. The province, and especially the town of Tzaneen, has a large number of sawmills which form an important part of the regional economy, providing a base to drive other subsectors, such as furniture making. About 63 000 ha of the province's landmass is under forest, with about 170 plantations producing more than 700 000 tonnes of timber a year. Approximately 680 000 m^3 of round wood is produced annually. Nearly 100 000 m^3 of this wood is used by companies in the mining sector. Pulp and paper production are not undertaken in the province.

The forestry sector is state sponsored and managed and, therefore, it is seen as one of the most strategic economic sectors with significant contribution towards continued economic growth and job creation. However, poor transport for agricultural products, shortage of necessary skills and few processing factories are the main challenges facing forestry sector in the district (Vhembe District Municipality, 2012).

Most companies in this industry ideally want to use rail (Transnet Freight Rail) as it can be the most cost effective transport mode. However, due to many challenges within TFR, such as inefficiencies, costs and quality of service overall, the shift from rail to road continues at an alarming pace (Limpopo Provincial Government, 2012). Less than 20% of companies use rail exclusively. The majority have either moved to road using reverse logistics for sharing freight costs and vehicles.

2.1.3.3 Manufacturing

The Limpopo province is not associated with heavy industry. However, there is a thriving manufacturing sector that leverages off the wealth of mineral and agricultural resources. Excellent manufacturing opportunities exist in tanning, fruit, vegetable and meat processing, brick, jewellery and furniture making, and industrial chemicals and light to medium engineering. Private sector investment is also being sought in the manufacturing and utilisation of magnesium oxide, cement, lime-based products, and granite (Limpopo Provincial Government, 2012).

In Greater Giyani, in terms of agro-processing business, the primary activity is value addition and post-harvest beneficiation of raw natural materials to produce commercial commodities that are sold to both domestic and international markets. Promising examples of agro-processing are, inter alia: Mopani worm processing enterprises, essential oils enterprises, beekeeping/honey production enterprises, oyster and mushroom production enterprises and small-scale commercial fishing and processing enterprises (www.greatergiyani.gov.za).

2.1.3.4 Mining

Buried beneath Limpopo's bushveld lie some of the world’s richest deposits of minerals, including the world's largest reserves of platinum group metals, as well as chromium, nickel, cobalt, vanadium, tin, limestone and uranium clay. Other natural resources include diamonds, gold, coal, copper, iron, lead, antinomy, phosphates, zinc, fluorspar, emeralds, scheelites, magnetite, vermiculite, amosite, andalusite, manganese, silicon, mica, black granite, corundum, feldspar, limestone, graphite, gypsum and salt (Limpopo Provincial Government, 2012).

Mining contributes about 30% to provincial gross domestic product (GDP) (Limpopo Provincial Government, 2012). According to the Chamber of Mines of South Africa, Limpopo is home to: the biggest diamond mine in South Africa (Venetia), the biggest copper mine in South Africa (Palamin), the biggest open-pit platinum mine in South Africa (RPM), the biggest vermiculite mine in the world (Foskor) and one of the major iron-ore producing mines in South Africa (Kumba).

In the Mopani District, antimony, copper and phosphate is mined (Limpopo Provincial Government, 2012). Most (95%) of the district’s mining happens in Ba-Phalaborwa, constituting 59.6% of the total district GDP (Ba-Phalaborwa Municipality, 2011)

The mineral occurrences and zones within the Vhembe district include: copper in the Messina fault, the Tshipise Magnesite field, the Mudimeli coal fields, the Tshipise, Pafuri and Mopane coal fields, the Beitbridge Complex

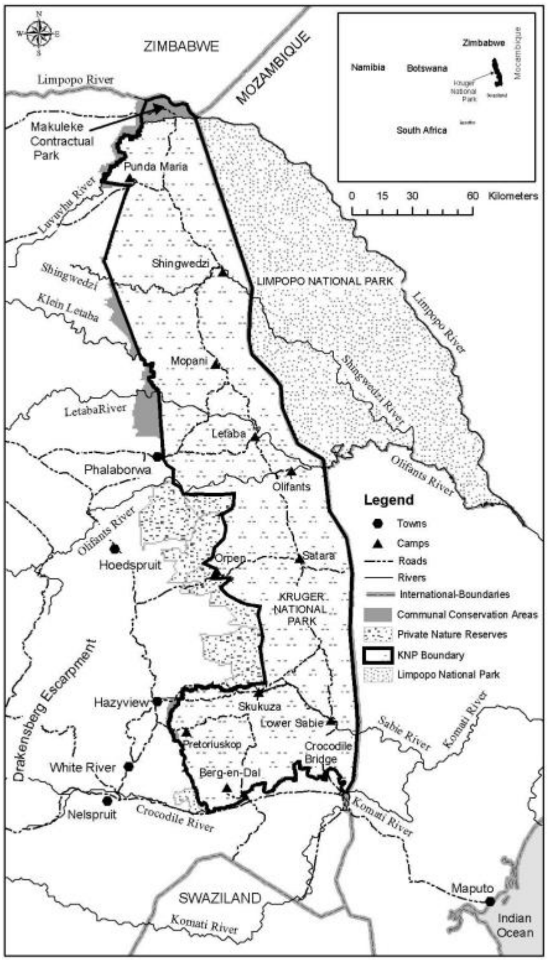
(Limpopo Belt) which hosts minerals ranging from iron and diamonds to graphite and marble, talc deposits, gemstone deposits and clay dominant minerals used in brick making (Vhembe District Municipality, 2012).

The mining industry uses the road, rail, and conveyor belts to transport the products to their destinations. Rail transports the largest volume of mineral products (Limpopo Provincial Government, 2012).

2.1.3.5 Tourism

The Limpopo province draws thousands of local and foreign visitors every year. And equally, the province attracts investors ready to take advantage of the steady stream of eco-tourists. Yet enormous potential still remains for growth in this area. There is plenty of opportunity for the independent hospitality provider interested in opening a smaller game lodge, bed and breakfast, restaurant, or similar business. There are no fewer than 53 state-owned nature conservancies with potential for local and foreign investment in terms of ownership, management and concessionary activity (Limpopo Provincial Government, 2012).

The most well-known of these nature reserves is the Kruger National Park (KNP) (Figure 2.10). The KNP acts as a de facto hub of economic (tourism) development in the Lowveld region. The KNP offers a variety of tourist accommodation and currently has 12 main rest camps, five bushveld camps, two bush lodges and four satellite camps; representing a total of more than 4100 beds (depending on maintenance, upgrades and various other circumstances) (Freitag-Ronaldson & Venter, 2008). There are also seven luxury lodges that have been granted concessions. The KNP is one of the world's most popular public entry game parks and receives in excess of one million visitors per year (Freitag-Ronaldson & Venter, 2008).



(Freitag-Ronaldson & Venter, 2008)

Figure 2.10 Map of the Kruger National Park

By partnering with neighbouring district municipalities, various external donors and neighbouring local communities, KNP has made good strides towards enabling better access to previously disadvantaged individuals and small micro-medium enterprises to KNP- related opportunities, ranging from biodiversity conservation, alien eradication (e.g. Working for Water), and arts and crafts, to the concessions programme (outsourcing catering and transport services to neighbouring communities of the KNP). Over the next five years, KNP will continue to support livelihood-based programmes, as well as co-operate with other livelihood-based initiatives such as the north-eastern escarpment bioregional plan (RESTORE programme), and those initiated by agencies such as Wits Rural Facility and NGOs (such as CESVI in the Giyani region) (Freitag-Ronaldson & Venter, 2008).

In the Vhembe district, there are 142 accommodation establishments, where 28% are graded as follows: three two-star accommodations, 23 three-star accommodations, 13 four-star accommodations and two five-star accommodations. The total number of beds available is 2 830, while the value of bed-nights sold per annum is R273m (Vhembe District Municipality, 2012). Most of the accommodations are found in Makhado and Musina. There are about 60 tourist guides registered to operate in Vhembe district. The district has three golf courses which are club based and an annual cycling event is held in Makhado. Curios are most found in areas with large volume of visitors likes Tshipise. The district has an advantage of having many crafters. The key tourism destinations in Vhembe District are: Vhembe Biosphere Reserve, Nwanedi Conservancy, Western Soutpansberg tourism plan, Lake Fundudzi, Matshakatini, Nandoni Dam, Breathing stone on Tswime mountain, Komatiland forests, Mutale gorge, Mukumbani waterfall, Tshatshingo Potholes, Mandadzi waterfall, Big Tree, Dongodzivha Dam, Tshavhadinda cave, Tshipise Sagole, Aventura Tshipise, archaeological and heritage sites and Transfrontier parks and the Mapungubwe heritage site (Vhembe District Municipality, 2012). There is one first division soccer team which brings about nine soccer matches per season to the district.

2.1.4 Environmental concerns in the region

The region has a wealth of natural resources which, unfortunately, is faced with a variety of challenges ranging from resources over-exploitation to land degradation. Sustainable development, which ensures efficient balance between social, economic and environmental needs, is of paramount importance in the region. Deforestation, erosion, invasion of alien species, rodents, insects and pests plague, drought, pollution, destabilisation of wetlands, wildfires, poaching and floods are main environmental challenges in the district.

2.1.4.1 Air pollution

All sources of air pollution in the Vhembe district are mainly industrial processes that involve burning coal, oil or other fuels, which causes serious air pollution (e.g. boilers, mineral processing, storage and handling, the inorganic chemicals industry and sawmills) (Vhembe District Municipality, 2012). Mobile sources are mostly associated with transportation and internal combustion engines with pollutants being emitted along the path taken. These emissions include gases and particulates from motor vehicles, road dust from unpaved surfaces, and road dust from paved surfaces.

Agricultural activities are the major contributor to air pollution in the Vhembe municipal area. Methane (CH_4) arises from animal dung, biological decay and fermentation in the stomachs of livestock. Vast quantities of dust are also generated during harvesting and ploughing. Pesticides (that kill insects) and herbicides (that kill weeds) are sprayed on crops to increase crop quality and quantity. These chemicals, however, remain in the soil and air, killing plants and animals and affecting the ecosystem. The spreading of nitrogen fertilizers on agricultural fields increases the content of nitrous oxide (NO_x) in the atmosphere. During winter accidental wild fires occurrence is very high and contribute to air pollution (Vhembe District Municipality, 2012).

Mining and its waste dumps are also responsible for air pollution in the district. Poorly managed coal mines can leak methane into the atmosphere, and coal waste dumps contains materials that can burn on their own (self-combustion) and produce poisonous particles and gases. Fugitive emissions from brickworks processes are contributors to air pollution, including dust fallout at mine and brick yards (Vhembe District Municipality, 2012).

2.1.4.2 Deforestation

Deforestation is one of the identified major environmental problems affecting most areas in the region. It is caused largely by traditional healers in pursuit of medicinal plants, wood carvers, firewood collectors, farmers and villagers residing around forest areas. The problem may be accelerated by poverty, lack of awareness on environmental services, unemployment, unclear land policy, lack of law enforcement, traditional practices and economic gains (Vhembe District Municipality, 2012).

2.1.4.3 Water scarcity and pollution

Water pollution is caused by littering and the over-flow of sewage, creating serious health problems for people who depend on water directly from rivers and streams (www.greatergiyani.gov.za). Informal businesses, like those conducted along the road to Moeketsi and Malamulele, worsen the problem by illegally dumping in the Klein Letaba River.

The water resources in the region are currently constrained and might not be able to cope with further development in the region.

2.1.4.4 Soil erosion

Environmental degradation remains a problem within numerous areas within the Mopani district. The loss of valuable topsoil to erosion and the subsequent siltation of rivers are difficult factors to rehabilitate. Soil erosion has increased in the area with the loss of grassland and wetland vegetation. The major causes of soil erosion are veld and forest fires, deforestation, overgrazing and poor land use planning and management. Clear-felling or uncontrolled burning of plantation compartments can also lead to increased soil erosion.

Storm water control systems and greening programmes need to be strengthened to fight soil erosion. The most affected land areas in Mopani are in Greater Letaba (Mokgwathi, Rotterdam, Bellevue, Serolorolo, Matswe, and Mamaila) and Greater Giyani (Khani, Ndhengeza, Shimange, Muyexe, Mavalane, Mninginisi). The other three municipalities in the Mopani district are experiencing soil erosion at minimal scale (Mopani District Municipality, 2013).

2.1.4.5 Natural habitat loss

Natural habitat is becoming increasingly fragmented and scarce in Giyani, as agricultural expansion, formal and informal housing settlements, and urban sprawl lead to large-scale clearing of bush, making it increasingly difficult for indigenous flora and fauna to survive (www.greatergiyani.gov.za).

2.1.4.6 Invasive alien species

Invasive alien plants present a major threat to the sustainability of greater Giyani. It is essential to eradicate these plant species as they consume vast amounts of scarce water resources (www.greatergiyani.gov.za).

2.1.4.7 Land-use adjacent to the Kruger National Park

Adjacent land-uses impact in various ways on the KNP and have to be incorporated in management considerations. Figure 2.11 shows the areas within which surrounding land-use changes could affect national parks. The zones serve as a basis for identifying focus areas in which park management should respond to development proposals and environmental impact analyses, identifying impacts that would be important at a particular site, and, most importantly, serving as the basis for integrating long-term protection of a national park into the spatial development plans of municipalities and other local authorities. The light blue zones on the map (Figure 2.11) are catchment protection areas. These are areas important for maintaining key hydrological processes within the park. Inappropriate development (dam construction, loss of riparian vegetation etc.) should be opposed (Freitag-Ronaldson & Venter, 2008). Control of alien vegetation and soil erosion, as well as appropriate land care, should be promoted. A large part of both the Vhembe and Mopani municipal districts fall within one of these catchment protection areas.

2.2 Transportation infrastructure in the Letaba basin

2.2.1 Roads

The Limpopo province has a total road network of about 22 200 kilometres, with 14% of national roads, 33% provincial roads and 53% local roads (Table 2.3). An estimated 31% is tarred and the rest is gravel and dirt roads. Less than 10% (about 310 km) of the SANRAL road network in Limpopo is tolled (the N1 section between the Carousel Plaza and Louis Trichardt). In Limpopo, there are 6 780 kilometres of surfaced roads, 15 219 kilometres of gravel or unpaved roads and 757 bridges. The bulk of unpaved roads are dirt roads situated in rural areas. There is a great need to increase number of kilometres of surfaced roads, to improve accessibility and mobility in the province.

Surfaced roads in the province are generally in a good condition, where about 30% of the network is rated as very good and about 36% being rated as good (Limpopo Provincial Government, 2012). Most bridges are in good condition, whilst a limited percentage are in a critical to marginal condition and need urgent attention. The funding for road infrastructure is always insufficient to adequately maintain the road network and provide equitable provision of access. The Limpopo Department of Roads and Transport has the following backlogs in terms of the provisioning of road infrastructure: an estimated R4 030 million in maintenance of surfaced roads, an estimated R67 billion in upgrading (gravel to surfaced standards), an estimated R 206 million in maintenance of bridges and an estimated R783 million in re-gravelling (Limpopo Provincial Government, 2012). These backlogs have a negative impact in the provisioning and maintenance of the road infrastructure. On average, about 3% of the paved road network is in a poor to very poor condition, with a further 27% in an average condition (Limpopo Provincial Government, 2012).

Table 2.3 Road classification split per province

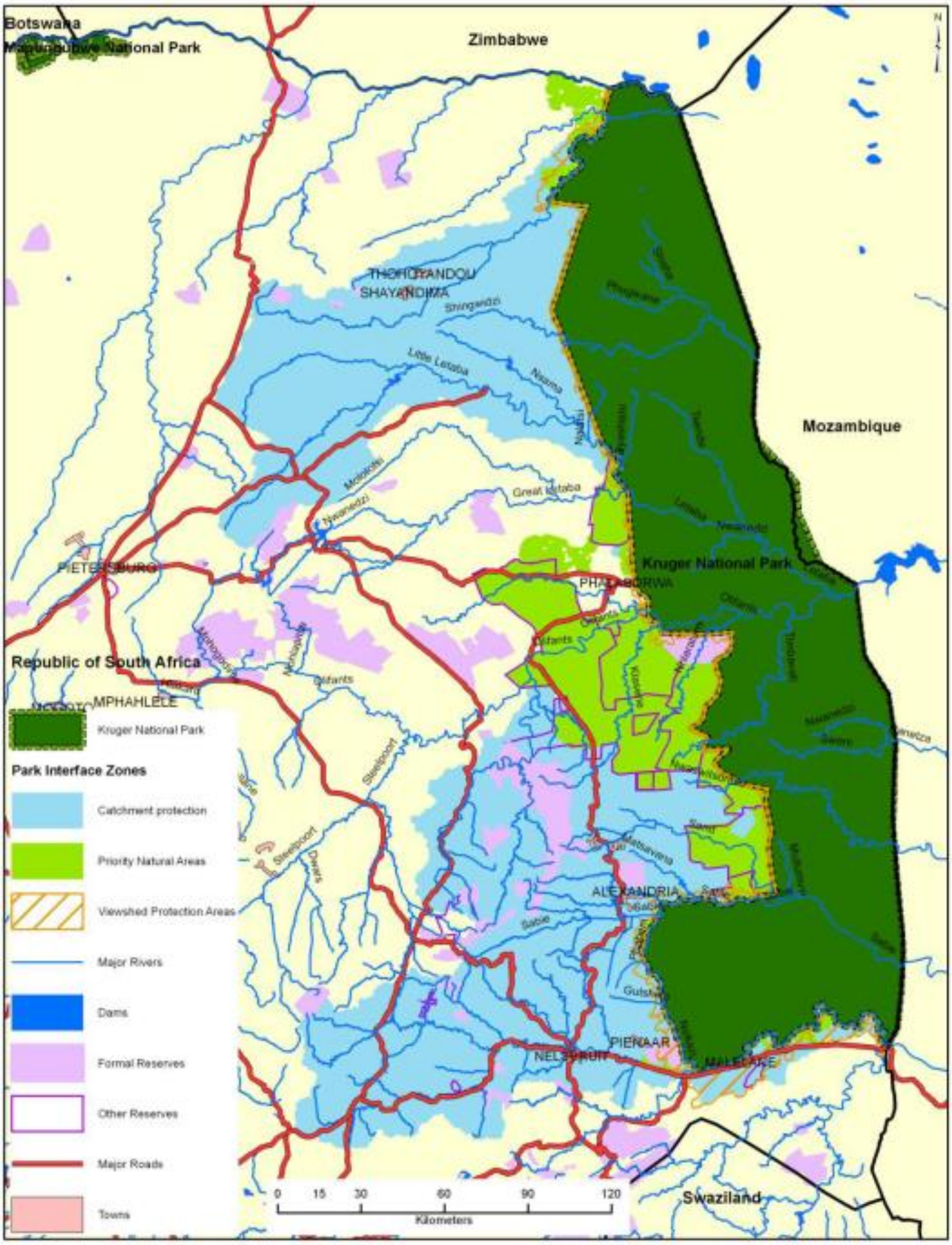
SUM OF ROAD LENGTH IN DIFFERENT PROVINCES

Provinces	Metropolitan	National	R2 (i.e. R21)	R3 (i.e. R574)	Total (km)
EC	7	1,858	3,009	3,841	8,713
FS	-	1,409	2,615	3,183	7,206
GP	77	713	1,006	1,084	2,878
KZ	29	1,105	1,872	1,579	4,583
LP	-	773	1,268	2,907	4,947
MP	-	1,227	1,858	1,906	4,991
NC	-	2,793	1,659	5,575	10,026
NW	-	1,315	985	2,728	5,027
WC	18	1,926	1,565	3,085	6,593
Total (km)	**130**	**13,115**	**15,834**	**25,883**	**54,961**

(Limpopo Provincial Government, 2012)

The biggest challenge for the province is to provide roads support - for the main corridors to link up with other provincial roads and, also, ultimately lead to the border posts including linkage to Maputo Corridor, Richards Bay and other major activity nodes. The principles should also include densification; shortened travel distance and time. Furthermore, the economic viability of each corridor development must focus on long-term employment and sustainable development, and to preferably favour local content (labour, materials and equipment), as well as projects that offer long term capital investments with the potential of low operating costs, that is high efficiency long term solutions.

The Mopani district municipality can be accessed via the following roads: the R36 to Modjadjiskloof, Tzaneen or Lydenburg, R40 to Gravelotte, Hoedspruit or Nelspruit, R71 to Haenertzburg, Tzaneen, Phalaborwa or Giriondo gate (South Africa/Mozambique border), R81 to Giyani, Mooketsi or Polokwane. The roads from Giyani to Phalaborwa and R529 Giyani to Tzaneen are additional to the main economic corridors in Mopani (Mopani District Municipality, 2013). The Phalaborwa Corridor connects Mpumalanga (Hazyview) with Phalaborwa and Tzaneen via smaller towns to the west of the Kruger National Park. The following road sections form part of the corridor. There are two core routes: route sections P17/3-5, D726, P112/1-3, P43/2, D1308 and P54/1; and road sections P146/1 from Klaserie to Blyde River, P116/1 from Hoedspruit to Ohrigstad via the Strijdom Tunnel, and P181/1 from the Oaks to Burgersfort (Mopani District Municipality, 2010). Some of the key roads in the Mopani district in terms of tourism are listed in Table 2.4.



(Freitag-Ronaldson & Venter, 2008)

Figure 2.11 Kruger National Park interface zones with neighbouring communities.

Table 2.4 Mopani district key tourism roads

Tourism spots	Name of roads	Comments/Activity
Kruger National Park	R71	Nature conservation and exit to Mozambique through Giriondo gate
Shangoni gate (KNP)	Giyani to Thomo to Shangoni D3641	Nature conservation
Modjadji Rain Queen	Mooketsi to Modjadji	Kingdom of Modjadji
Kruger to Canyon biosphere	R36	Nature conservation
Phunda Maria gate (KNP)	R81	Nature conservation
Echo caves	R527	Heritage/historic sites

(Mopani District Municipality, 2010)

The Mopani district area has 3135.5 kilometres of roads. In the Greater Tzaneen Municipality the total length of tarred roads is 439.56 km and gravel roads is 593.4 km. The grand total kilometres of roads in the Greater Tzaneen area is 1033 km. For Greater Letaba municipality, the distance of tarred roads is 150.5 km, whereas, the distance of gravel roads is 535.7 km; the total kilometres for the entire municipal area is 657.2 km. The kilometres of tarred roads in the Greater Giyani municipality are 113 km and the gravel roads distance is 605.8 km, totalling 718 km for the entire municipality. The Ba-Phalaborwa Municipality has roads totalling 489.96 km, with 223.7 km of tarred roads as opposed to 266.2 km of gravel roads. In total, 975.1 km of these roads are tarred and 2149.8 km are gravel (Limpopo Provincial Government, 2012). The state of roads in the district have an impact on the economic development of the area as it is clear that most roads, leading to where the majority of the district population is, are not tarred, and, as such, hinder the proper transportation of people, goods and services to these areas.

According to the latest assessment in 2007, the average visual conditions of roads in Mopani yielded “fair” (Mopani District Municipality, 2010). Most of the gravel roads are not maintained regularly. In addition to that, some of the roads in the district do not have route names and numbers. They also do not have appropriate road signs (e.g. speed limits), as well as signs indicating distances between destinations. Another problematic issue on the district roads is that, in most areas, fencing along the routes has been removed. This has resulted in wild and domestic animals wandering on the roads with detrimental effect to motorists, and thus, negating our tourism attraction efforts as a region. Many road accidents in the district can be attributed to animals roaming on the roads (Limpopo Provincial Government, 2012).

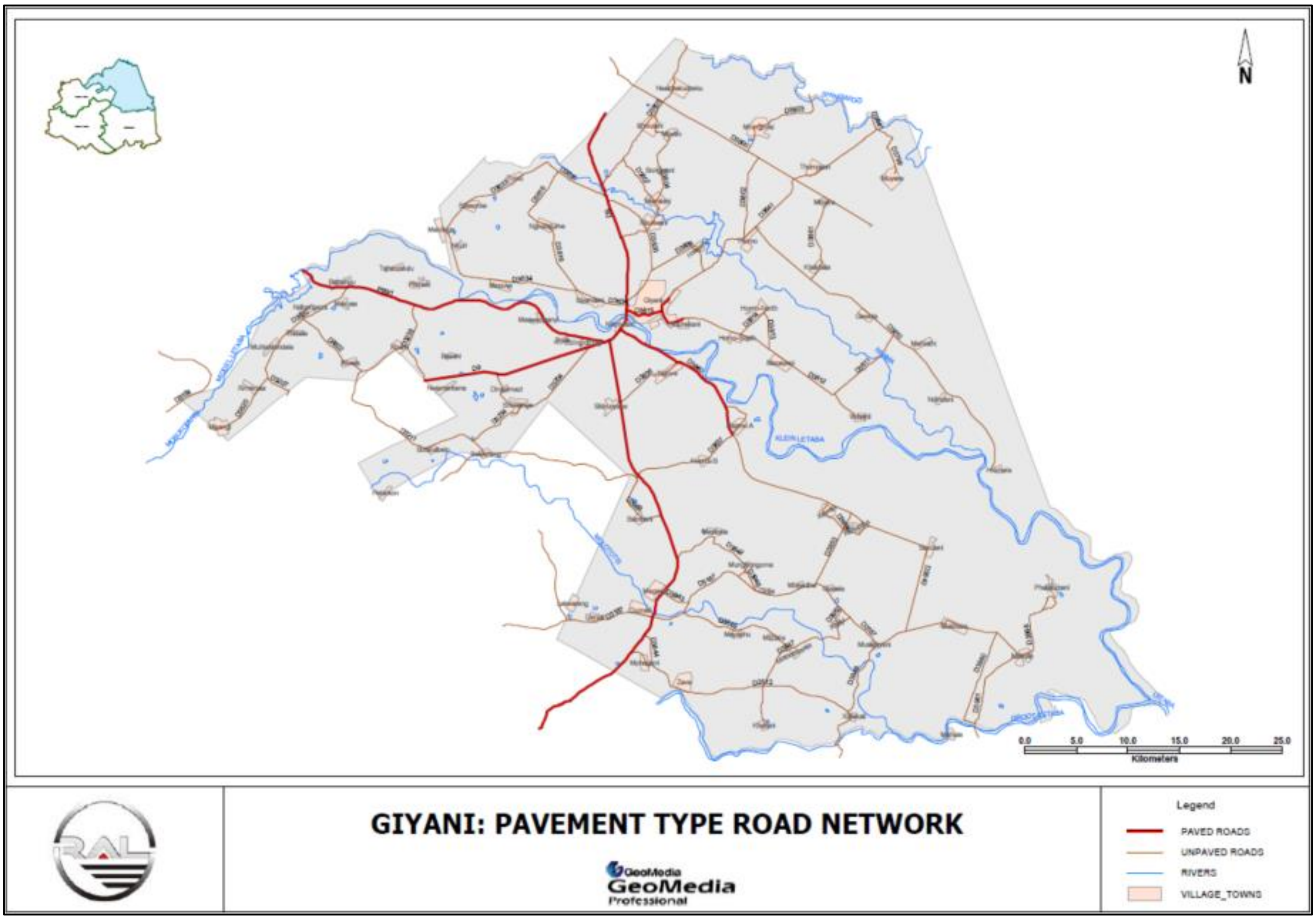
In the Vhembe district municipality, the National road (N1) covers 150 km of surfaced road, while provincial roads covers 762.2 km of surfaced and 1145.47 km of gravel roads in the district. The district surfaced roads cover 153.48 km and gravel 2021 km (Limpopo Provincial Government, 2012). The total length of provincial roads is 3 940 km in the district, of which 37% of roads are tarred/paved. The total length of gravel roads is 2 469 km (Vhembe District Municipality, 2012).

2.2.1.1 Greater Giyani municipality

Giyani has 79 km of provincial tarred road and 608 km of gravel road. Most of the roads need rehabilitation and maintenance and bridges need to be repaired. The roads are either linkages to strategic destinations or are freight and economic corridors (Greater Giyani Municipality, 2012/13).

The key challenges to the local municipality are the lack of resources, heavy rainfalls and a poor storm drainage system. Most streets in Giyani, with the exception of Kremetart, have no names. This creates problems for tourists, businesses, emergency services and police services. Road and information signs are also critical in the municipal area (Greater Giyani Municipality, 2012/13). The municipality is responsible to maintain and rehabilitate 1365 km of roads. In 2009/2010 they maintained 424 km of roads (Greater Giyani Municipality, 2009).

Muyexe, a village in the Greater Giyani area known as the poorest village in South Africa, the transportation infrastructure is dismal. The Mail & Guardian (Molele, 2013) reports that minibus taxi drivers often refuse to take passengers into the village, because the long road to the rural, dusty and impoverished Limpopo village of Muyexe damages their vehicles. If residents walk, they risk being attacked by wild animals that escape from the nearby Kruger National Park. Women, however, have to walk for several kilometres to collect drinking water from a dam and to collect firewood, which they carry on their heads. The village has no infrastructure such as tarred roads, running water, sanitation, adequate housing or electricity. A bus goes to Muyexe twice a day, but people say they often have to use donkey carts to travel between villages (Molele, 2013). Figure 2.13 displays the road network in the Greater Giyani municipal area.



(http://www.ral.co.za)

Figure 2.12 Giyani road network

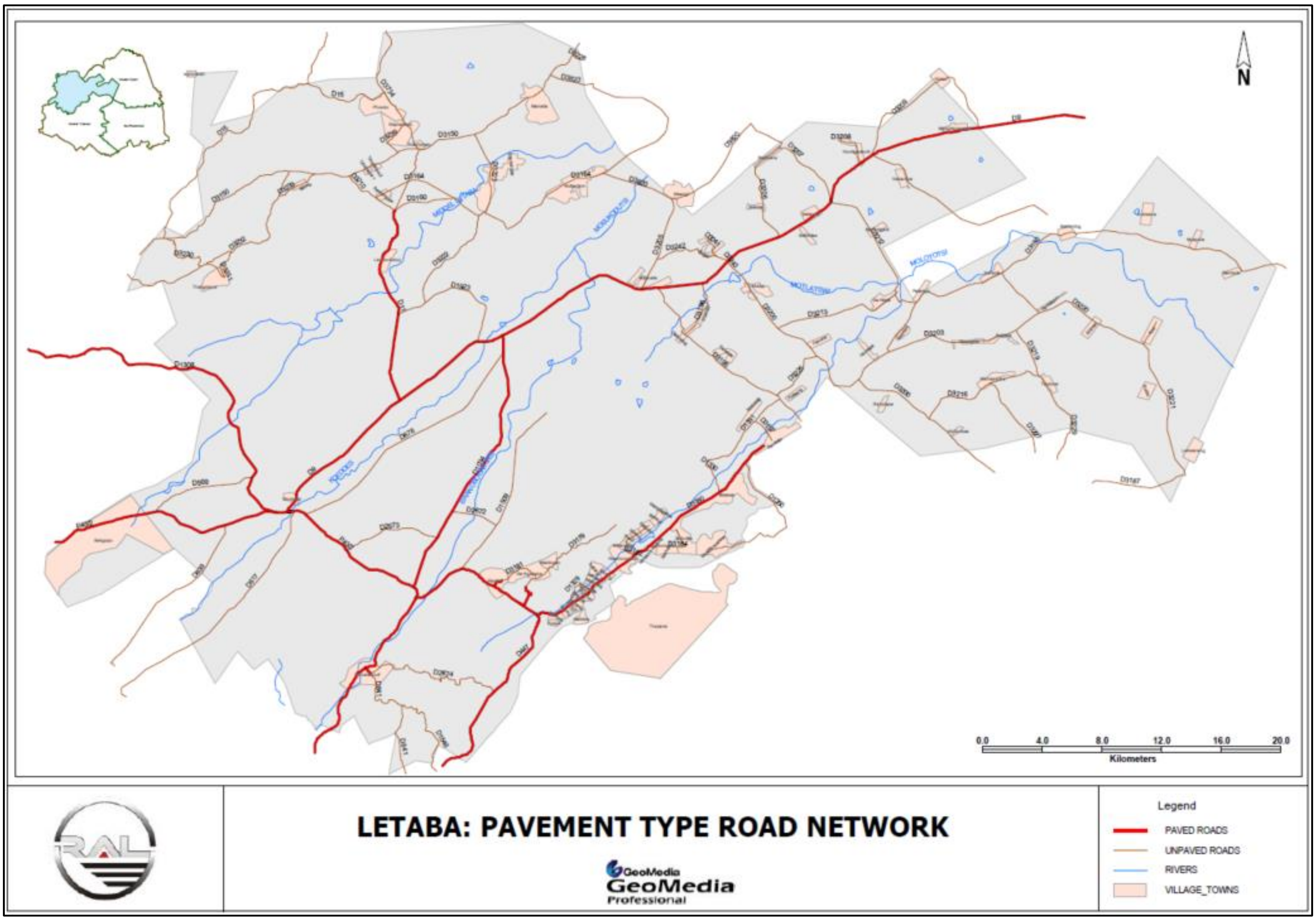
2.2.1.2 Greater Letaba municipality

The municipality is able to maintain 484 km of roads, but has a 729 km road maintenance backlog (Greater Letaba Municipality, 2012). Figure 2.13 displays the road network in the Greater Letaba municipal area.

2.2.1.3 Greater Tzaneen municipality

Table 2.5 indicates the road maintenance and development activities of the Greater Tzaneen municipality between 2008 and 2013. (http://www.ral.co.za)

Figure 2.14 displays the road network in the Greater Tzaneen municipal area.



(http://www.ral.co.za)

Figure 2.13 Letaba road network

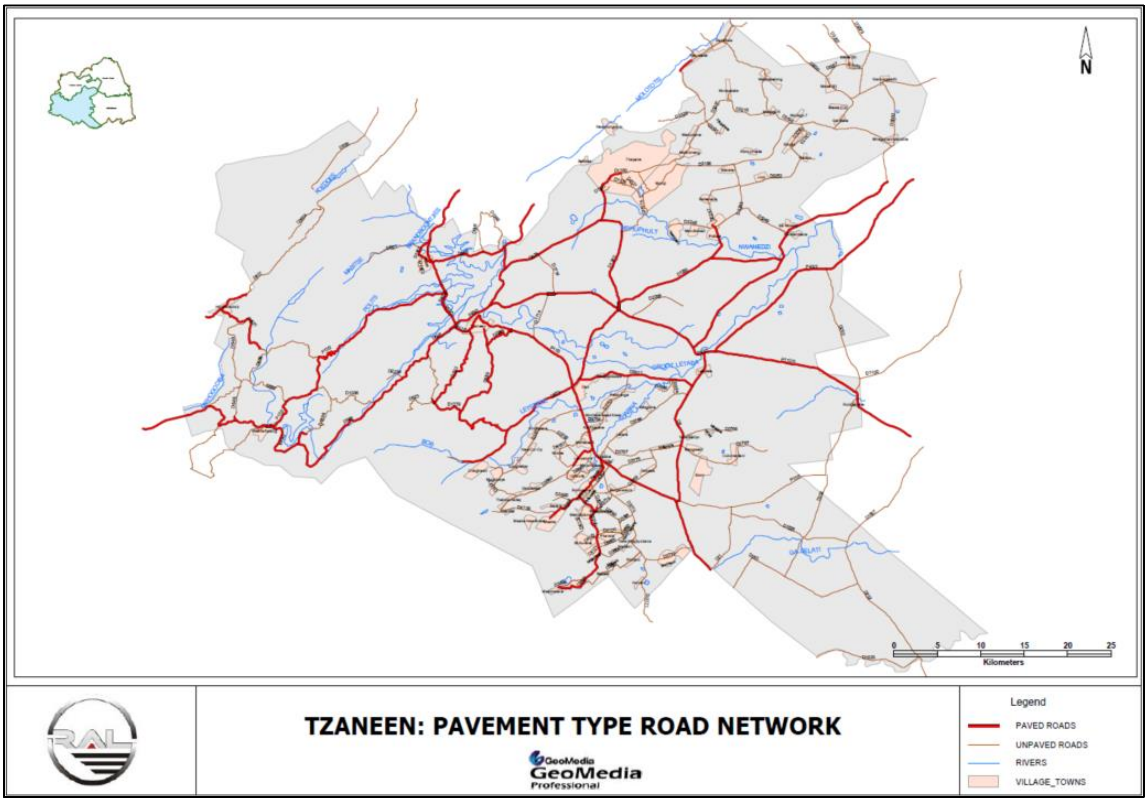
Table 2.5 Road infrastructure management by the Greater Tzaneen municipality

Table 48: Road infrastructure 2008/09 - 2012/13								
Year	Gravel				Tar/Asphalted			
	Total km	Newly constructed	Upgraded to tar	Maintained	Total km	Newly constructed	Re-sheeted	Maintained
2008/2009	1610	13.14	0	1779	690	0	0	0
2009/2010	1610	14.73	0	1610	690	0	0	0
2010/2011	1610	0	0	1478	690	0	0	0
2011/2012	1610	0	0	1824	690	0	0	56 727 m^2
2012/2013	1610	0	0	2355	690	0	0	7594 m^2

(Greater Tzaneen Municipality, 2012)

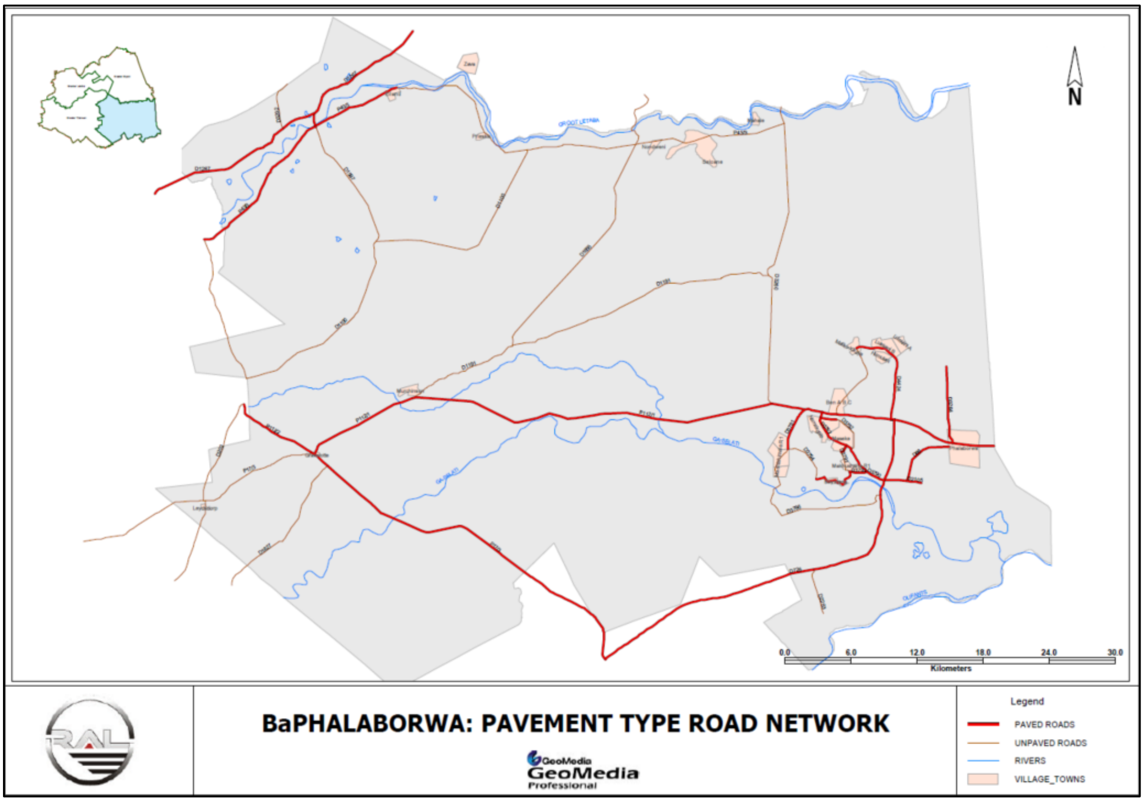
2.2.1.4 Ba-Phalaborwa municipality

From 2011 to 2012, 3.5 km of a targeted 5 km of new roads were constructed in the area. A further 37 km of roads were patched and resealed. The entire municipal roads capital budget was spent (Ba-Phalaborwa Municipality, 2011). Figure 2.15 displays the road network in the Ba-Phalaborwa municipal area.



(http://www.ral.co.za)

Figure 2.14 Tzaneen road network



(http://www.ral.co.za)

Figure 2.15 Ba-Phalaborwa road network

2.2.1.5 Thulamela municipality

Some 40 km of streets were gravelled in Thulamela municipality in 2011. In the same year, 6.9 km of municipal roads were developed (Thulamela Municipality, 2011). An overview of the road infrastructure in the municipality is provided in Table 2.6, Table 2.7 and Figure 2.16.

Table 2.6 Gravel road infrastructure in the Thulamela municipality

Gravel Road Infrastructure Kilometres				
	Total gravel roads	New gravel roads constructed	Gravel roads upgraded to asphalt	Gravel roads graded /maintained
2009/10	No data	None	16,8km	
2010/11	No data	None	2009/10 carried 2010/11	
2011/12	No data	6.9km	14.6km	1091 km

(Thulamela Municipality, 2011)

Table 2.7 Asphalted road infrastructure in the Thulamela municipality

Asphalted Road Infrastructure Kilometres					
	Total asphalted roads	New asphalt roads	Existing asphalt roads re-asphalted	Existing asphalt roads re-sheeted	Asphalt roads maintained
2009/10	151,36	16,8km		-	
2010/11	151,36	N/A	11,6	-	
2011/12	165,36	N/A	11km	-	11km

(Thulamela Municipality, 2011)

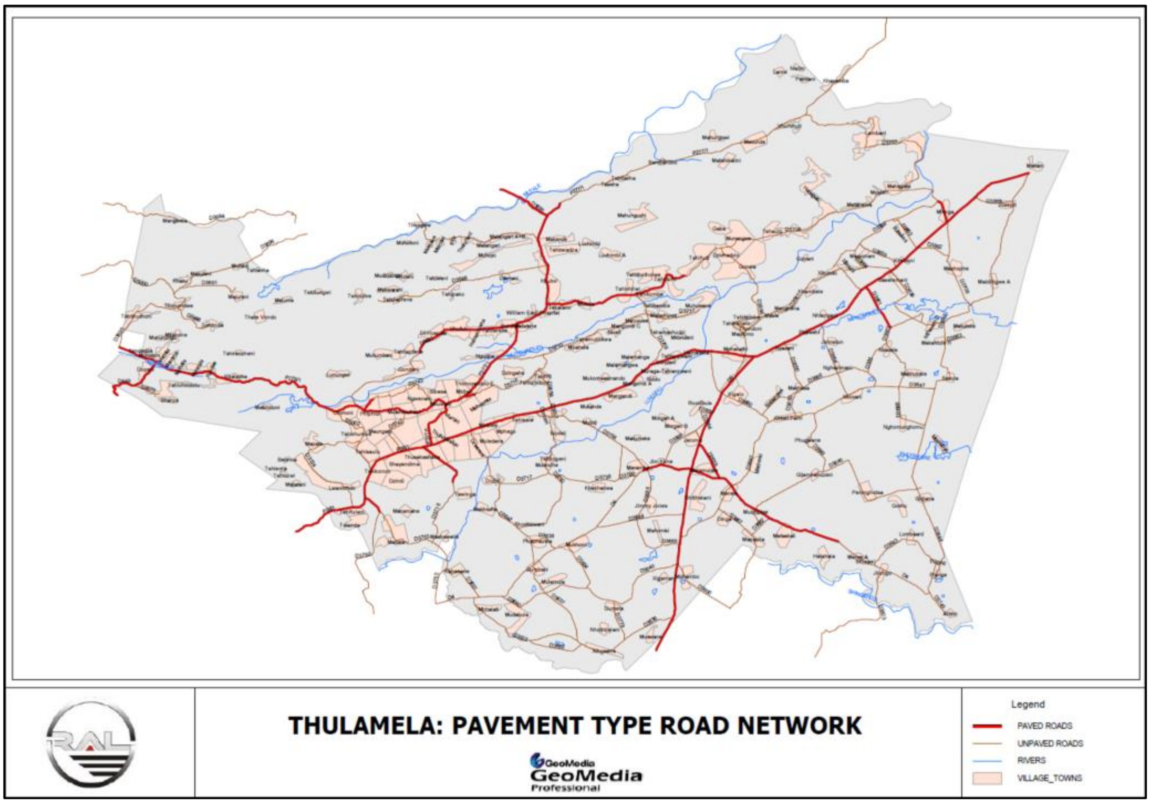
2.2.1.6 Makhado municipality

In Makhado, most of the roads linking villages are gravelled, lack proper maintenance and cannot be used in very wet conditions. In general, the roads in Makhado municipal area are in a bad condition and require upgrading, especially in summer seasons during heavy rainfalls. The total road and storm water management system backlog is estimated at approximately 4400 km (Makhado Local Municipality, 2012). Municipal performance in terms of road maintenance is noted in Table 2.8. Figure 2.17 displays the road network in the Makhado municipal area.

Table 2.8 Municipal road infrastructure in Makhado

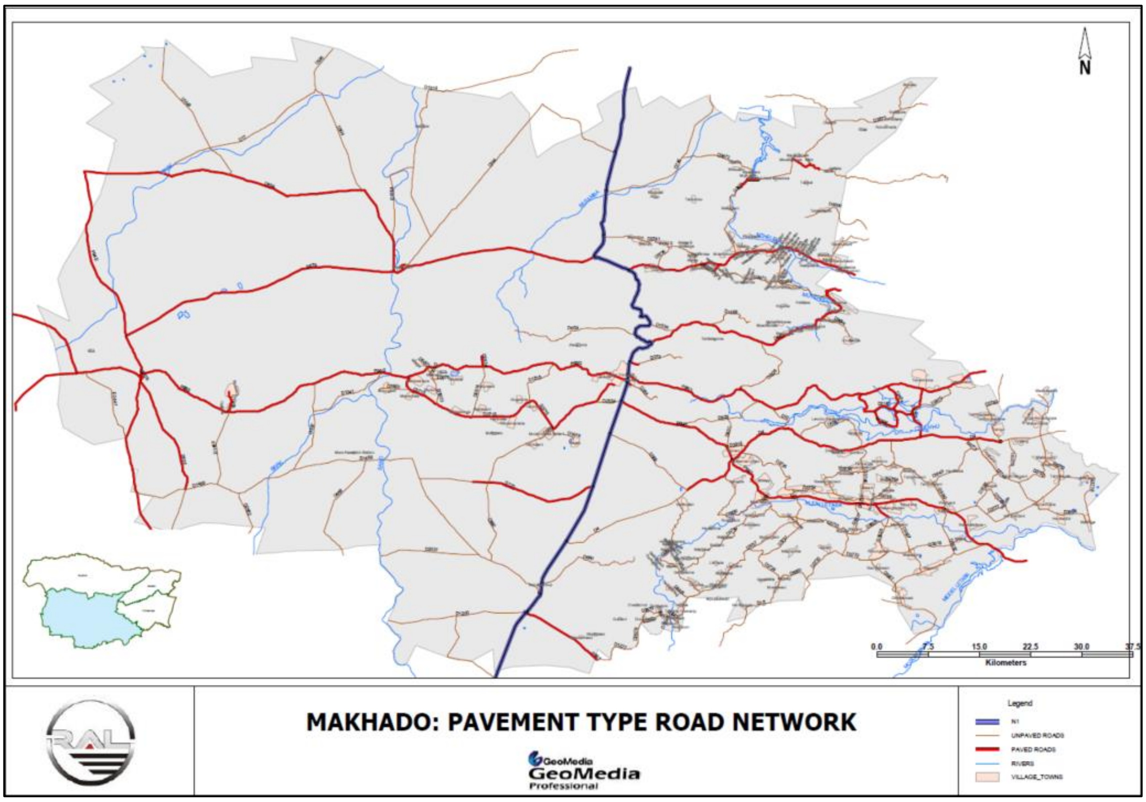
Gravel Road Infrastructure Kilometres				
	Total gravel roads	New gravel roads constructed	Gravel roads upgraded to asphalt	Gravel roads graded /maintained
2009/10	4400km	0	8km	
2010/11	4392	0	21.8KM	6014KIM
2011/12	4370	0	12KM	6014km
2012/13	4347	0	23km	3445km

(Makhado Local Municipality, 2012)



(http://www.ral.co.za)

Figure 2.16 Thulamela road network



(http://www.ral.co.za)

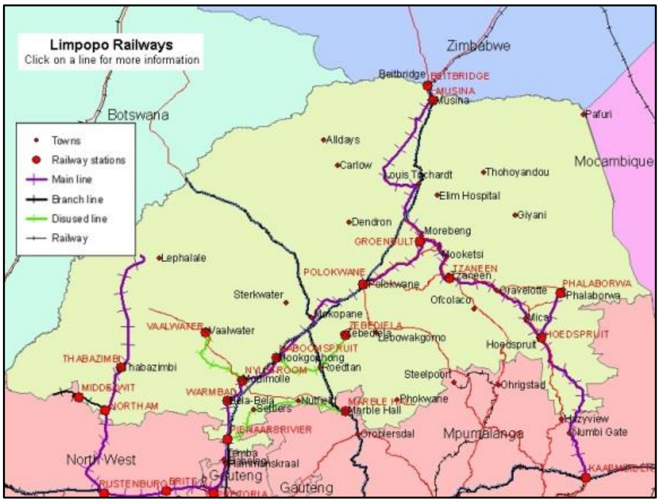
Figure 2.17 Makhado road network

2.2.2 Rail

The rail freight system in Limpopo is a crucial element of the South African transportation system and is a significant factor in the movement of freight within the province and through the province to destinations in the interior - both within and beyond South African borders (Limpopo Provincial Government, 2012). There are three important main lines (Figure 2.18), namely: the Pyramid South (Pretoria) to Beitbridge line, which connects with the Zimbabwean system and points north to Dar es Salaam. The second important line is the branch from Pyramid South to Lephalale, serving coal, iron ore and chrome mines. The third is the arterial line from Goudplaas on the Beitbridge line, running south-eastwards to the Maputo line at Kaapmuiden. It serves the Tzaneen, Letsitele agricultural area in the north and the mining area on the Phalaborwa branch in the south.

There used to be three agricultural branches running from the Beitbridge line but they have all closed in recent years, despite there still being traffic potential which could benefit if they were to be re-opened in the future (Limpopo Provincial Government, 2012).

The Kaapmuiden to Groenbult line is electrified at 3 kV and operated by CTC between Kaapmuiden and Phalaborwa. Diesel traction is used to Tzaneen and Groenbult. The 65 km section from Kaapmuiden to Hazyview and Mkhuhlu falls within Mpumalanga Province. At the Phalaborwa marshalling yard a train control officer dispatches over 15 trains a day. Class 18E electric locomotives are used on trains and they are operated from Komatipoort. It is, however, planned to use new 41 Class diesel-electric locomotives which are coming into service on through loads to Richards Bay going forward (Limpopo Provincial Government, 2012).



(Limpopo Provincial Government, 2012)

Figure 2.18 Limpopo Province rail network

2.2.3 Aviation

Although there are airfields distributed throughout the province, air transportation to most parts of the province remain a challenge as the, majority of the airfields are operated by the general aviation community, offering mainly chartered flights and flying lessons. Limpopo has three airports in two district municipalities that offer commercial scheduled flights and a deterministic means of air cargo transportation (Limpopo Provincial Government, 2012).

2.2.3.1 Giyani airport

Greater Giyani municipality has an airport that was developed by the former Gazankulu Government. The airport has not been adequately utilised, due to poor and unmaintained infrastructure. However, Gateway Airports Authority Limited (GAAL) has indicated plans to upgrade and maintain the airport. The municipality must still put strategies in place to market and promote the airport (Greater Giyani Municipality, 2012/13).

2.2.3.2 Hoedspruit airport

Eastgate (Hoedspruit) airport is located seven nautical miles to the east of the town of Hoedspruit and it is partly owned by the South African Air Force (SAAF). The airport is currently operated by SA EXPRESS, which runs two daily flights from Johannesburg (OR Tambo) and a daily flight to Cape Town (Limpopo Provincial Government, 2012).

2.2.3.3 Phalaborwa airport

Kruger Gateway (Phalaborwa) airport is located one nautical mile to the north east of the town of Phalaborwa and has a single 1373 x 18 m runway, suitable for aircraft with a seating capacity not exceeding 29 passengers. The airport is owned by Phalaborwa Airport (Pty) Ltd in which SA AIRLINK has ownership rights. The airport offers AIRLINK operated daily scheduled flights from Johannesburg (OR Tambo) and it is mainly used by mining executives and the South African National Defence Force (Limpopo Provincial Government, 2012).

2.2.3.4 Tzaneen municipal airfield

Tzaneen municipal airfield is owned by the Greater Tzaneen local municipality and is located ten nautical miles to the east of the town of Tzaneen. The airport is mainly used by private individuals, most of which belong to Letaba Flying Club; some of whom are business people who use their private aircraft to fly to Gauteng and other destinations in South Africa for business purposes. There are currently no scheduled passenger services and no recorded movements of passengers or aircraft. From the number of hangers at the facility, one can tell that it is quite busy (Limpopo Provincial Government, 2012).

2.2.4 Pipelines

Pipeline transport is the transportation of goods through the mode of "pipe networks". Products moved in this manner include liquefied commodities (crude oil, diesel, petrol, jet fuels) and gases (methane rich gas). In terms of "gases" it is mostly for gases deemed "stable" and safe to be conveyed via pipelines. There are no major freight pipelines identified in the province (Limpopo Provincial Government, 2012).

2.2.5 Water-based transport

There is no maritime port in the Limpopo province, nor any significant water-based transport.

2.2.6 Intermodal facilities

One intermodal facility is situated in the vicinity of the Foskor and Phalaborwa Mining (PMC) companies. It is operated by the Container and Automotive Business division in Transnet. Currently, about 99.5% of the commodities handled at the facility are mining products from PMC and Foskor. These mineral products are transported in containers and are destined for the Durban and Maputo harbours for export. The intermodal facility currently dispatches about 400 containers per month, whilst the facility can handle about 45 containers per day at full capacity. For handling of containers, the facility has one reach stacker, two mobile cranes, and two forklifts. The reach stacker is used as the main operating equipment, whilst the mobile cranes and the forklifts are on standby to assist when required. The yard can store up to 300 containers. There are management offices onsite. The facility operates from 6 am to 6 pm, Monday to Friday. When there is a need, the facility also operates on weekends. There is a 24 hour security service on the premises (Limpopo Provincial Government, 2012).

Another potential intermodal facility is located at the Tzaneen station. There are no facilities dedicated to the handling of goods on site. The area is solely used for the loading of citrus fruits during the months of May, June, and July only, and thereafter there are other activities in the area that could utilise such a facility (Limpopo Provincial Government, 2012).

2.2.7 Border crossings

There are eight border posts in the province, however, only Groblersbrug and Beitbridge carries freight. Neither of these border posts fall within the study area. The Giriyondo border crossing in the Kruger National Park can be accessed through the study area.

2.3 Transportation activity in the Letaba basin

2.3.1 Passenger transportation

Car ownership per household in the Mopani district is 21.6% and 34.4% of households in the Vhembe district owns cars (Department of Transport, 2003). Table 2.9 and Table 2.10 provide an overview of the trip purpose splits in each district. It can be seen that non-motorised transport is widely used in these regions.

Table 2.9 Mopani district average number of trips per person per day according to purpose

Mopani	Work	Education	Shop	Lookwork	Medical	Welfare	Visit	Sport	Church	Other	Home
Train	0	0.005874	0.001728	0.001728	0	0	0.004838	0.000346	0	0.000346	0.014858
Bus	0.004492	0	0.021424	0	0	0	0	0	0	0.000346	0.026261
Mtaxi	0.000346	0.012785	0	0	0	0	0	0.001037	0	0	0.014167
Minibustaxi	0.006565	0.000346	0.000346	0	0	0	0.001037	0	0	0	0.008293
Sedantaxi	0	0	0.002419	0	0.000346	0	0	0	0	0.002419	0.005183
Bakkietaxi	0	0.004492	0	0	0	0	0	0	0.004838	0.001728	0.011057
Car	0.002419	0.000346	0	0	0	0	0	0.003801	0.002073	0	0.008639
Truck	0.000346	0	0.000346	0	0	0	0.010366	0.002764	0	0	0.013822
Motor	0	0.002419	0	0	0	0	0.006911	0	0	0	0.00933
Bike	0.000346	0.000691	0	0	0.001728	0	0	0	0.000691	0.005529	0.008984
Other	0	0	0	0.000346	0.000346	0	0	0.006565	0.013476	0	0.020733
Walk	0.101244	0.402211	0.166551	0.009675	0.023151	0.015895	0.236351	0.093642	0.015895	0.029717	1.094333

(Department of Transport, 2003)

Table 2.10 Vhembe district average number of trips per person per day according to purpose

Vhembe	Work	Education	Shop	Lookwork	Medical	Welfare	Visit	Sport	Church	Other	Home
Train	0	0.006543	0.000545	0.001636	0	0	0.009269	0	0	0	0.017993
Bus	0.004362	0.001091	0.013086	0	0	0	0.001636	0	0.000545	0	0.02072
Mtaxi	0	0.019084	0	0	0.003272	0	0	0.001636	0	0	0.023991
Minibustaxi	0.009269	0	0	0.001091	0.000545	0	0.001636	0	0	0	0.012541
Sedantaxi	0	0	0.007088	0	0	0	0.000545	0	0	0.019629	0.027263
Bakkietaxi	0	0.005998	0.001636	0	0	0	0	0	0.01036	0.01145	0.029444
Car	0.003272	0	0	0	0	0	0	0.025627	0.004907	0	0.033806
Truck	0.001636	0	0.002181	0	0	0	0.055071	0.018539	0	0	0.077426
Motor	0	0.002726	0.000545	0	0	0.001636	0.04253	0	0	0.001091	0.048528
Bike	0	0.001636	0	0	0.005453	0.001091	0	0	0.000545	0.007634	0.016358
Other	0.000545	0	0	0.002181	0.002726	0	0.000545	0.012541	0.009269	0.000545	0.028353
Walk	0.094329	0.40458	0.105234	0.010905	0.006543	0.001636	0.160305	0.113959	0.007634	0.013631	0.918757

(Department of Transport, 2003)

2.3.1.1 Road-based public transport

In South Africa, the poor typically live far away from job opportunities and access to amenities. This burdens the workforce with enormous travel distances to their places of employment and commercial centres, and, thus, with excessive costs. There are also inadequate public transport infrequencies and route coverage, poor coordination, and service infrequencies. The Mopani District Municipal area is characterised by inadequate public transport, despite the fact that the majority of the population is reliant on buses (Mopani District Municipality, 2013). Generally the available modes of transport are not up to standard, nor safe, reliable, affordable or accessible. The public transport needs of the disabled are also not catered for. There is an oversupply of taxis on tarred roads and an undersupply of taxis on rural gravelled roads; leaving these areas fully dependent on “bakkies”.

Bus services throughout the district are unreliable and not available in certain areas, this is worsened by bad road conditions. The Ba-Phalaborwa municipality, for example, experiences a serious scarcity of transport. This is as a result of the withdrawal of the former subsidised Lebowa Transport Services, leaving the general public reliant on expensive taxis. Formal and informal taxi ranks needs to be upgraded or refurbished in order to meet the standards of the incoming taxi fleet through the Taxi Recapitalisation Programme, and facilities should be user friendly in terms of catering for the disabled. As population increases, the number of travellers will also increase. The majority will be unable to use private transport and will be dependent on public transport. Given the need for increased mobility and the cost and environmental impact of accommodating private motorists, the future emphasis is on the provision of safe, convenient, affordable public transport (Mopani District Municipality, 2013).

Table 2.11 Taxi facilities in the Mopani District

SPREAD OF TAXI FACILITIES IN THE MOPANI DISTRICT				
Municipality	Number of formal minibus taxi facilities	Number of informal minibus taxi facilities	Total number of minibus taxi facilities	Percentage of informal facilities
Ba-Phalaborwa	1	9	10	90%
Greater Giyani	4	10	14	71%
Greater Letaba	4	7	11	64%
Greater Tzaneen	3	20	23	87%
Maruleng	4	2	6	33%

(Mopani District Municipality, 2013)

As many of the facilities in the district are informal (see Table 2.11), implying that they do not possess the necessary facilities and that it is virtually impossible to determine the rank utilisation. The state of taxi ranks in Mopani District is as follows (Mopani District Municipality, 2013): 51% are on-street facilities, 85.2% are informal, 7.4% have lighting, 16% are paved, 9.9% have public telephones, 2.5% have offices, 14.8% have shelters and 15% have ablution blocks.

The major bus termini in the Mopani district is limited to Tzaneen, Modjadjiskloof, Giyani and Phalaborwa (Mopani District Municipality, 2013). Most of these bus terminals are also without adequate facilities (shelters, toilets, ticket sales points etc.). The public transport demand in the district cannot be met by the provision of services by the current bus operators, due to the vastness of the area and the condition of, particularly, gravel roads in the district.

In Giyani, there is a fleet of more than 40 buses, which have been distributed all over Greater Giyani Municipal area. The buses serving the area are augmented by long distance buses, which are other privately owned bus companies which transport commuters from Giyani to Gauteng. There are private bus companies, which assist in conveying commuters to and from work on a daily basis, e.g. Risaba Bus Service and John Hlungwane, as well as approximately 500 taxis. Most people get to work or school on foot (44%), while 2.4% use minibus taxis (Greater Giyani Municipality, 2012/13).

Table 2.12 summarises the extent of public transport services in the Vhembe district municipality. The major public transport corridors in the region are listed in Table 2.13. There are three formal and eight informal bus ranks in the district. Additionally, there are eleven formal taxi ranks of which two are in the Makhado municipality and six in

Thulamela. There are 19 informal taxi ranks in the district (Vhembe District Municipality, 2012). Figure 2.19 and Figure 2.20 illustrate the routes of the subsidised bus operation corridors in the Thulamela and Makhado municipal areas, respectively.

Table 2.12 Public transport overview for the Vhembe district

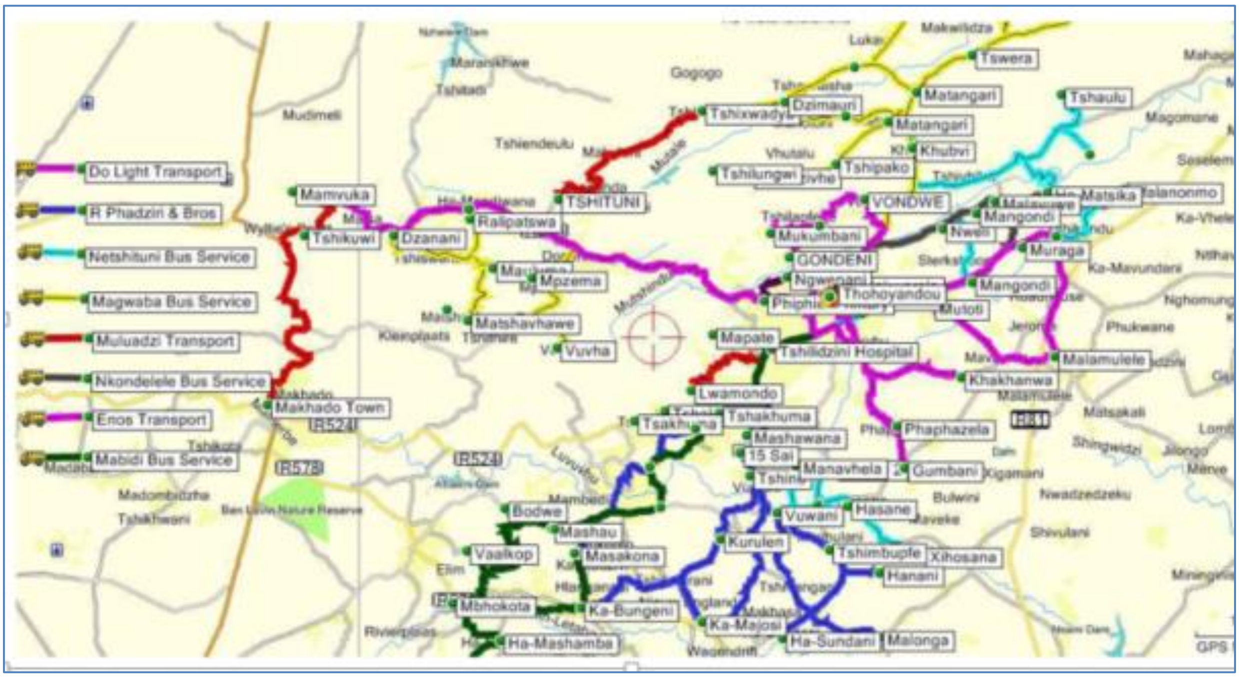
MUNICIPALITIES	NO. OF TAXIS	TAXI ROUTES	NO. OF BUSES	SUBSIDISED BUS ROUTES
THULAMELA	1 258	132	248	147
MAKHADO	1 191	105	304	86
MUSINA	482	21	13	0
MUTALE	216	14	11	8
VDM	**2 865**	**272**	**500**	**241**
TAXI Association: 18 & TAXI Council: 01			**Bus Association: 01**	

(Vhembe District Municipality, 2012)

Table 2.13 Major public transport routes in the Vhembe district

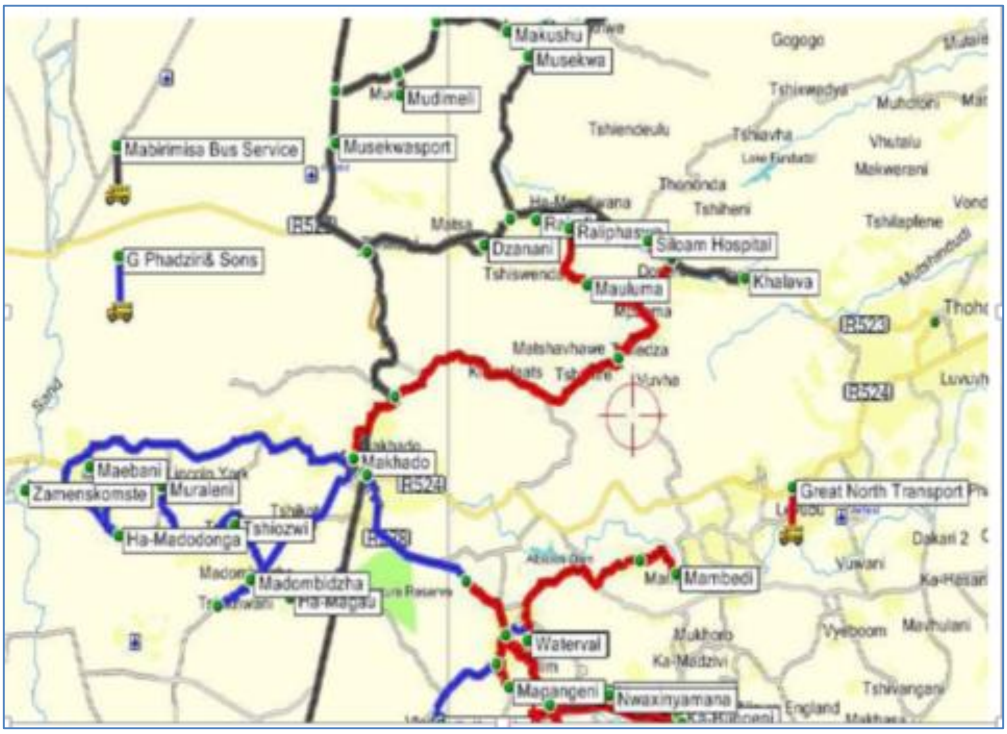
ROUTE CODE	CORRIDOR ROUTE
Makhado to Ndzhelele	Along the N1 North from Louis Trichardt and turn right along Road R523 to Ndzhelele
Makhado to Elim	Along the N1 South from Makhado and turn left along Road R578 to Elim
Makhado to Midoroni	Along Road R522 south west from Makhado to Midoroni/Maebane
Musina to Nancefield and Beit Bridge	Along the N1 North from Musina to Beit Bridge
Elim to Giyani	Along Road R578
Thohoyandou to Tshakuma	Along Road R524
Thohoyandou to Ndzhelele	Along Road R523
Thohoyandou to Mutale	Along Road R523
Thohoyandou to Tshaulu	Along Road R523
Thohoyandou to Malamulele	Along Road R524 north from Thohoyandou and turn right to R81 to Malamulele
Basani to Saselamani	Along Road R524
Malamulele to Giant reefs	Along a gravel road south east from Malamulele up to Giant Reefs
Malamulele to Giyani	Along Road R81
Bungeni to Giyani	Along Road R578

(Vhembe District Municipality, 2012)



(Vhembe District Municipality, 2012)

Figure 2.19 Tshivase and Thohoyandou subsidised corridor bus operation



(Vhembe District Municipality, 2012)

Figure 2.20 Makhado subsidised corridor bus operation

2.3.1.2 Rail passenger transport

There is no more usage of railway train operations as a mode of public transport within the district (Mopani District Municipality, 2013).

Table 2.14 Operational statistics for Phalaborwa airport

KRUGER PARK GATEWAY AIRPORT

	2009			2010			2011	
	SCHEDULED			SCHEDULED			SCHEDULED	
	FLIGHTS	PASSENGERS		FLIGHTS	PASSENGERS		FLIGHTS	PASSENGERS
Sep	64	828		71	1 246		54	964
Oct	74	1 055		74	1 249		57	1 098
Nov	69	881		73	1 153		56	957
Dec	59	817		52	743		43	680
Jan	67	850		52	821		53	844
Feb	69	923		52	839		42	926
Mar	74	1 056		57	1 014		73	1 114
Apr	58	897		52	965		65	979
May	67	963		57	876		67	975
Jun	69	942		59	835		66	951
Jul	72	1 170		60	929		72	1 226
Aug	73	1 284		58	1 141		74	1 260
Total	**815**	**11 666**		**717**	**11 811**		**722**	**11 974**

(Limpopo Provincial Government, 2012)

2.3.1.3 Air transport

Passenger movements at Phalaborwa airport are dominated by those travelling in scheduled flights, the majority of whom are business people mainly going to the mines situated in the area (Limpopo Provincial Government, 2012). Phalaborwa airport handles about 1000 aircraft movements (take-off and landing included) and about 12 000 passengers (arriving and departing included) annually (Table 2.14).

It is estimated that Hoedspruit airport handles more passengers than Phalaborwa, but currently there is no data available to prove this fact (Limpopo Provincial Government, 2012). Over 95% of the passengers are tourists visiting the Kruger National Park and other game reserves in the area - especially Kapama Game Reserve, which has a stake in the airport.

2.3.2 Freight transportation activity

2.3.2.1 Road freight

Currently, road transport is the most used mode of transport in Limpopo. This is in line with the national trend. According to the State of Logistics Survey for South Africa, in 2010, road freight constituted 88.7% of all freight movement in the country, whilst the rail freight constituted 11.3%. The choice of road as a means of freight transport is influenced, in some instances, by: reliability of mode, time to reach destination, safety of goods, and ease of access to collection or delivery points.

Road freight volumes in Limpopo are expected to change over time, with major corridors handling increased general cargo and some reduction in the localised transportation of coal. The major freight transport routes in the Vhembe district are the N1 National Road from Polokwane to Beitbridge, the R522 from Vivo to Makhado, the R523 from Vivo via Waterpoort to Masekwapoort, the R521 from Vivo to Pont drift Border, the R572 from Musina to Pont drift, the R524 from the Makhado central business district to Punda Maria, the R81 from road R524 to Giyani, the R525 from Mopani, the N1 Road to Pafuri Gate and the R578 from Giyani via Elim to the N1 National Road (Vhembe District Municipality, 2012).

2.3.2.2 Rail freight

During the 2011 calendar, year over 17 million tons of general freight cargo was transported by rail across Limpopo. Of this total, just over a half million tons consisted of transit traffic, moving through Gauteng Province to Beitbridge and points further north. It can, therefore, be seen that rail is a significant provider of transportation capacity;

however, its market share of general freight traffic has is declined in recent years (Limpopo Provincial Government, 2012).

The Phalaborwa branch section of the line generated over 5 million tons of traffic during the 2011 review period. About 2.2 million tons was rock phosphate traffic and 3.6 million tons was magnetite (Limpopo Provincial Government, 2012). The section north of Hoedspruit has almost been relegated to that of a light traffic density arterial route, but it forms part of an alternative line to the Pretoria - Beitbridge main line for traffic between KwaZulu Natal and points north of the border. For this reason it is a strategically important route. In addition to transit traffic, citrus fruit traffic is sourced from various points, some of which moves north to Groenbult and some moves to the south via Kaapmuiden and points beyond. Table 2.15 shows the rail freight volumes moved on the Groenbult – Kaapmuiden line in 2011.

Table 2.15 Rail freight tonnages moved on the Groenbult-Kaapmuiden line in 2011

Groenbult - Tzaneen - Phalaborwa - Kaapmuiden

Fwd Tons:	Net tonnage forwarded (Generated) from provincial stations to other provinces or for export
Rec. Tons:	Net tonnage received at provincial staions from other provinces or imported
Prov. Intrastate:	Traffic forwarded from one station to another within the province.
Transit Tons:	this traffic is not generated or received at any Limpopo stations, it must be seen as "bridge" traffic transiting the province.

	Fwd Tons	Rec. Tons	Prov. Intrastate	Transit Tons	Total Tons
Agriculture	3087	0	0	0	3087
Mining	6032265	0	0	0	6032265
Manufacturing	16874	28785	0	0	45659
Container Traffic	72403	11	0	0	72414
Total	6124629	28796	0	0	6153425

(Limpopo Provincial Government, 2012)

2.3.2.3 Air freight

Air freight at Phalaborwa airport is carried in scheduled AIRLINK flights from Johannesburg and mainly is destined for mining companies in the vicinity. The air freight consists mainly of documents, machine spares and accessories, as well as animals (mainly cats and dogs). Cargo is carried with passenger luggage and it is collected chiefly by courier companies at the airport who take it to its destination point. Air freight information presented for Phalaborwa airport clearly shows imports leading exports by a far margin. For the period under consideration, a total of 3824 kilograms of import cargo arrived at Phalaborwa airport, at an average of 478 kilograms per month. In the same period, a total of 2133 kilograms of export cargo left the airport, at an average of 266 kilograms per month (Limpopo Provincial Government, 2012). Eastgate airport is a tourist oriented airport facility and, as such, has got almost zero air freight going through its terminals (Limpopo Provincial Government, 2012).

3. Development prospects in the Letaba basin

3.1 Economic development

The Mopani district municipality was identified as the most important development point in the Limpopo Province for tourism and business attraction, due to the diverse range of activities and natural splendour found there (Mopani District Municipality, 2013). The vision for the development of the Mopani district is: "Mopani district, as a whole, will create a favourable environment to ensure that out of the whole of Southern Africa, the Mopani district will supply the largest part of food (fruit, vegetables, nuts, meat [mainly game] produce and products) to the local, national and international market. This will create extra-ordinary economic growth for the whole district, emanating in the improvement of the quality of life of all citizens and also enable the local municipalities to be financially viable and to provide quality services. Due to the diverse vegetation within the district, ranging from sub-tropical, tropical to bush-veld, as well as the fact that it falls within the gateway to the Kruger National Park and Mozambique, it creates the ideal opportunity to promote the District as the tourist growth point in the Limpopo Province". There are, however, a number of factors impacting negatively on the economic growth, such as geographical location (distance to markets), shortage of skills, poor infrastructure, climatic conditions and diseases (HIV and malaria).

A provincial economic development study in 2000 identified tourism, agriculture, mining and trade and manufacturing as sectors with a potential for growth in the Mopani district (Mopani District Municipality, 2010). The key spatial opportunities identified in Mopani include the following: abutting with Mozambique to afford Mopani citizens proximity to access the beaches in Xaixai, Baleni, etc. and also to make Mopani a gateway to the Giriondo Border post. There is vast land in rural areas for agricultural purposes. The close proximity to the Great Limpopo Transfrontier Park and internationally acclaimed Kruger National Park can be leveraged to strengthen tourism (Mopani District Municipality, 2013).

In Greater Giyani there has been some growth in the agriculture sector from 1996 to 2001. The most noticeable growth was in the transport and communication sector. The GDP grew from 1.12% in 1996 to 12.91% in 2001 in this sector. The population living in urban areas also increased from 10.1% in 1996 to 13.8% in 2001 and to 20.5% in 2007 (Mopani District Municipality, 2013). It can be expected that all these growth trends will continue as the South African economy develops. The following are the niche areas for economic development in Giyani: Mopani worms, opening of the Shangoni gate, revitalising abandoned farms and unlocking the tourism potential of the cultural values celebrated in the area (Mopani District Municipality, 2013).

The town of Muyexe falls within the Greater Giyani area. During his first State of the Nation address in 2009, President Jacob Zuma announced plans to turn Muyexe into a model of rural development. The local chief, Khazamula Maluleka, summed up the situation (Molele, 2013). More than three years after they were promised a clinic, library, tourism centre, shopping mall, hotel and tarred road, most of the projects did not even have funding, let alone having been started. Projects to develop a paving plant, hotel, mall, police station, library and other infrastructure have collapsed, due to lack of funding. "Land surveyors came here the other day to prepare for the construction of a tarred road through our village but nothing has been done. The new road is supposed to connect us with the Shangoni Gate of the Kruger National Park and will create much-needed jobs along the corridor. But we are still waiting for the authorities," indicates Maluleka. As Muyexe remains high on the government agenda, there is hope that at some point these proposed developments will come to fruition in the region.

The Department of Transport has indicated that a transport facility in the amount of R150 million will be built in Giyani. This will serve as a taxi and bus rank with chain shops. Presently, the project is at the design stage and the only challenge is land where the facility will be built. However, the site has been identified for this purpose (Greater Giyani Municipality, 2012/13).

In Greater Letaba, the GDP of the agriculture sector (including forestry) has grown somewhat from 20.8% in 1996 to 21% in 2001. Along with this sector, the transport and communications sector has also grown from 18.3% to 20.7%.These are the only sectors in which growth was indicated and are, thus, the most important economic sectors in the area. The following are the niche areas for economic development in the municipality exist: the depot of tomato production and exportation, the African ivory route, the biggest Baobab tree, timber production and the legend of Modjadji, the Rain Queen (Mopani District Municipality, 2013).

Greater Tzaneen is the municipality with the largest population in the district with 39% of the population residing there. The municipality also has a high percentage of economically active population (53.1%). Although agriculture is by far the most important sector in this area, Greater Tzaneen also has the highest percentage of GDP of each of its sectors, except for mining, of all the municipalities. The GDP in the agricultural sector has grown from 55.9% to 59%, indicating its growing importance. The contribution to GDP from the manufacturing sector has decreased, although the agricultural sector has grown. This might be due to the fact that most of the produce is exported out of the area for processing. This creates an opportunity for manufacturing to be exploited within the area. The following niche areas for economic development have been identified by the district municipality (Mopani District Municipality, 2013): cultural heritage sites, nature based and agro-tourism, adventure, sport and event route tourism, the Tzaneen and Ebenezer dams and the tallest tree at Magoebaskloof (48 m high).

Ba-Phalaborwa has the most concentrated economy of all the local municipalities, due to its large mining sector. Linked to this sector is also the manufacturing sector, which has also grown in contribution to the GDP. The transport sector grew by 15% in GDP from 1996 to 2001 and the manufacturing sector grew by 10.8%. The economy of Ba-Phalaborwa is very sensitive to changes in the mining sector and all sectors connected to mining should be exploited for development. The following are the mining niche areas for economic development: Magnetite, Copper, Vermiculite, Nickel, Apatite, Zirconium, Titanium, Uranium, Clay and Mica (Mopani District Municipality, 2013). There are moves to diversify the Ba-Phalaborwa economy to alternative economic sectors such as tourism, agriculture, and manufacturing (Ba-Phalaborwa Municipality, 2011).

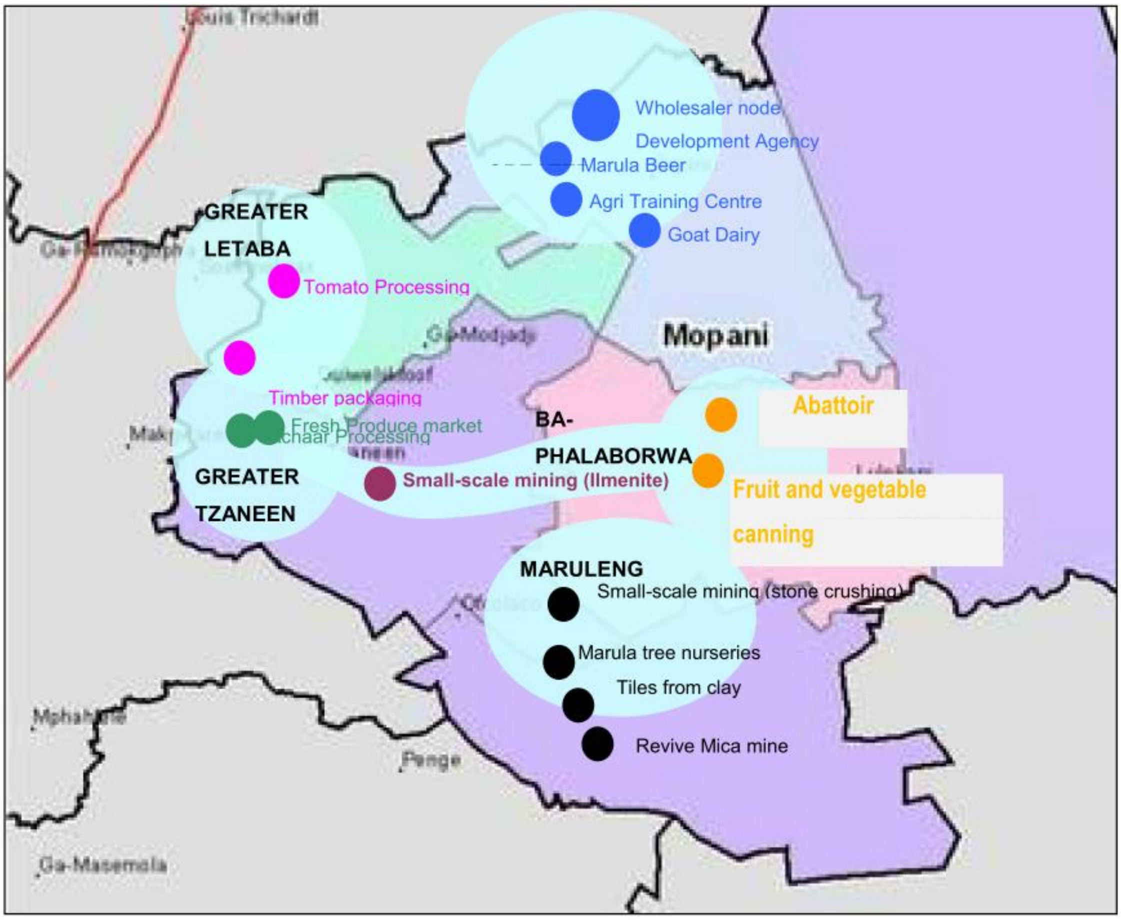
In light of the key sectors identified in the Mopani district and the existing opportunities identified, seven strategic thrusts for economic development were developed and are showcased in Figure 3.1. A plaza shopping centre is being established at Tikiline (Greater Tzaneen) and another underway at Metz (Malumele). These are bringing economic activities and decent jobs closer to people's place of residence, thus transforming the legacy of the past (Mopani District Municipality, 2013). A number of roads have been established and paved to increase rural access which allows economic activities to take place in those areas. Table 3.1 lists the key roads identified that will be critical in supporting the planned development initiatives within the district.

Table 3.1 Roads poised for development in the Mopani district

Table: Roads within District Growth Points in Mopani District Municipality

Description	Distance (km)	Road No.	Road Responsibility & Authority
Giyani to Nkuri to Malonga to Hanani to Tshimbupfe to Vuwani	48	D3634,D3778,D3753,D3718	Provincial
Giyani to Thomo to Altein to Shangoni kruger national park gate	8	D3641	Provincial
Thomo/Altein(Shangoni KNP Gate) to Khakhala to Gawula to Khakhala to Mahlathi to Ndindani to Hlomela to Phalaubeni to Mbaula to Phalaborwa	34	D3810	Provincial
Mageva to Gija to Mbendle to Guwela to Kheyi to Mushiyani	26	D3843,D3187	District
Sikiming to Mbebula to Nkomo (Modjadji Mokwakwaila Mbebula to Nkomo).serves a large number for community and shopping	25	D3180,D3837	Provincial

(Limpopo Provincial Government, 2012)



(Mopani District Municipality, 2013)

Figure 3.1 Key development initiatives to be promoted in the Mopani district

The Vhembe local economic development strategy, in turn, depicts that the district economic growth potential is in agriculture, tourism and mining (Vhembe District Municipality, 2012). Feasibility studies have been done on the following projects: Footsteps of Ancestors; poultry abattoirs; development of sugar industry; agriculture equipment lending depot; development of fish farming; preservation of dried fruit/vegetables; goats milk dairy products; fruit based soap production, Mutale goats farming and beneficiation of forestry products. All these initiatives require funds to be implemented - the availability of funds will determine implementation time.

3.1.1 Agriculture

According to M'Marete (2006), 17.1% of the land in the Letaba catchment is arable in terms of soil suitability and 48.5% is classified as marginal. According to the Limpopo Growth Development Strategy, the objectives of the Limpopo province, with regards to agricultural development, are tripling the size of agriculture by 2015, increasing the value of agriculture through enterprise diversification, investing in water saving technologies and adding value within the agro-value chain (Limpopo Provincial Government, 2012).

The Greater Giyani municipality of the Limpopo Province has been selected as the EAU4Food pilot site in South Africa. This area was earmarked for development by the national Comprehensive Rural Development Programme aimed at fostering business enterprises, land reform and agrarian transformation (Querner & Froebrich, 2014).

In the Vhembe district, the Thulamela area has the most areas with fertile soil for crop farming (as indicated by the brown regions in Figure 2.5) (Thulamela Municipality, 2011). Opportunities for the agricultural sector in Thulamela are based on existing developments that can be exploited further (Vhembe District Municipality, 2012):

- The abundance of oil producing crops, such as avocadoes, can be utilised for biodiesel production through oil extraction from avocadoes;
- The existing production of mangoes, oranges and tomatoes can be leveraged for fruit processing (achaar etc.), vegetable processing or expanded on the fresh produce market;
- Water sources can be used for aquaculture establishment, and to support the growth of stevia and sugar cane around Nandoni Dam;
- Existing livestock farming (cattle, goats, poultry) can support abattoir establishment, meat processing and dairy processing from goat milk;
- The forestry cluster can be leveraged for the expansion of saw mills, carpentry and coffin making, to grow medicinal plants, to boost tea production and mushroom harvesting.

Constraints that need to be addressed in Thulamela's agricultural sector are the lack of access to capital to fund the start-up cost of capital intensive agro-processing projects, the lack of skilled workers for management and growth of projects, the lack of markets for produce (due to rigorous demands of private companies), the high cost of transport for bulky items, land claims on the area, the lack of skills and experience, the lack of formalised, organised, reliable freight transit for perishable goods, the lack of market access particularly for livestock farmers, the age of people employed in the agri-industry and access for tourists to agricultural attractions (Vhembe District Municipality, 2012).

Opportunities to develop the agricultural sector in Makhado are (Vhembe District Municipality, 2012):

- Utilising existing water sources for aquaculture production;
- Utilising existing livestock (cattle, goat, milk) for more abattoir establishment, meat processing and dairy processing ;
- Existing production of bananas, mangoes, citrus, tomatoes, garlic and pepper, avocado oil production can expand fruit processing (achaar), the fresh produce market, macadamia nut processing and packaging plants, and organic farming;
- Bee farming and the forestry cluster can provide wood for the construction industry, support furniture manufacturing and be used as medicinal plants.

Constraints that need to be addressed in Makhado's agricultural sector are the land claims on the area, the lack of access to initial capital, the lack of marketing, the lack of infrastructure for small scale farmers, the average age of people employed in the agri-industry and access for tourists to agricultural attractions (Vhembe District Municipality, 2012).

To improve the economic and social situation of the rural communities, many subsistence farmers are entering the commercial farming industry (van Breda, 2014). If managed properly, this could improve the economic and social condition of the area, as well as help in securing food security. However, without proper planning and management this could have a negative impact on the water security of the area. Alexander et al. (2010) also indicated that agricultural development could have harmful impacts on the environment in the Letaba region and specifically on the Kruger National Park.

3.1.2 Mining

The Phalaborwa Spatial Development Initiative (SDI), linking the port of Maputo and Richards Bay to the mining in Phalaborwa, is one untapped potential development that would increase wealth to Mopani, as trading would increase between these areas where raw mining materials are processed (Mopani District Municipality, 2010). In the Vhembe district, the following mining-related opportunities have been identified (Vhembe District Municipality, 2012):

- Supply manufacturing inputs to existing mines (Makhado and Thulamela),
- Sub-contract cleaning and catering services to existing mines (Makhado and Thulamela),
- Initiating small scale mining cooperatives (Makhado and Thulamela),

- Initiating coal beneficiation practices (Makhado),
- Tombstone manufacturing from low grade talc (Makhado),
- Water filtration using garnet crystals (Makhado),
- Initiating gemstone production endeavours (Makhado),
- Expanding brick production capacity (Makhado and Thulamela), and
- Expanding concrete production (Thulamela).

3.1.3 Tourism

With a prime national park, nature reserves and game farms covering almost half of the district, the Mopani district has been identified as one of the five best conserved ecosystems in the world, providing ample opportunity for Eco Tourism and development (Mopani District Municipality, 2010). The district has a large number of diverse, under-exploited tourism assets, e.g. the northern portion of the KNP. One of the major boosts for tourism in the Mopani district is the planned opening of a new access gate (the Shangoni gate) to the Kruger National Park in the Greater Giyani municipality. The new gate makes it about 90 km from the Shingwedzi camp to Giyani (via the Shangoni gate), whilst it is more or less 190 km if one uses the Punda Maria Gate. The proposed new gate would physically be in the Thulamela local municipality, but the main access road would be via Giyani (which falls under Greater Giyani local municipality).

Nomsa Khandlhele, the head of Local Economic Development in Giyani, said the project would be a huge boost to the municipality in terms of creating jobs. “We view this project as an opportunity for us to create a platform for our local business people to develop and do more businesses that will create more jobs”. According to Kruger National Park managing director Abby Sibiya, “the road will halve tourists’ traffic for both Phalaborwa Gate and Phunda Maria Gate in Thulamela municipality, since it is in the middle.” The local authorities feel that the project is going to be significant, because diverting tourism traffic to Shangoni Gate is going to accelerate development in the communities along the access road by creating jobs.

It is envisioned that the well-constructed road network will be busy, with tourists driving to and from the KNP to buy food, crafts and other goods and services from the numerous locally owned and operated shops, markets, stalls, entertainment facilities, guest houses and historical sites. The local residents will be moving to and from work and delivering or buying goods for trade. The villages will be transformed into attractive and functional places, which offer the whole range of basic social and economic opportunities associated with a "sustainable human settlement" where people can live, work and play. The improved access for tourists that will be brought about by the development of roads and bridges to the Shangoni Gate will be extended to a network that will serve three villages (Altein, Mninginisi, and Muyexe) and integrate them into the tourism value chain and mainstream of regional social and economic development. The improved access will entice many other investments by government and private sector in infrastructure and facilities and generally improve service delivery in the area with visible impacts on livelihoods, health, life expectancy, education, skills levels and enterprise development, which sets the scene for sustainable growth into the future. Additionally, the development will improve the link between South Africa and Mozambique and as a gateway to the Great Limpopo Transfrontier Park. In this way, the development will connect communities, municipalities and countries. This vision is entrenched in the IDC Development Charter signed by all project stakeholder representatives in September 2012.

Other developments are also planned for the KNP. In June 2011, the Minister of Water and Environmental Affairs responded to question 1564 in the National Assembly that SANParks plans to build more low impact rustic Tsendze style tented camps in the future. He indicated that the list of concepts, which are currently in the early planning stage, include the following: a rustic camp site on the upper Shingwedzi River where the envisaged Shangoni Gate and corridor is being planned, a rustic camp (tented possibly) in the Pafuri and/or Punda Maria area and a rustic camp (tented) on the northern bank of the Letaba River. These are, however, all at a pre-feasibility phase and the final decision in terms of design and location have not been made.

In the rest of Giyani, the Middle Letaba and Nsami dam offers opportunities for water sports and fishing. The statue of Nghunghunyani, which is situated at the banks of Letaba River and Maombe nature reserve offer some impetus to the tourism industry. There is an estimated 300 beds distributed amongst 20 bed and breakfasts; lodges; and hotels in the municipality (Greater Giyani Municipality, 2012/13). Some 70% of these facilities are found in town or very close to town. These facilities offer clients outstanding service at reasonable rates.

The Vhembe region has real, authentic and mostly unspoilt tourism resources. The scenery ranges from subtropical and mountainous to the unspoiled bushveld and majestic Baobabs. It has real people, real animals, real live culture and historical sites that hold the myths and legends of ancestors and forefathers. The challenges that affect tourism development are: the implementation of the "Footsteps of the ancestor" business plan, formation of the Regional tourism association, operation of Awelani eco-tourism project and upgrading of roads to tourism hotspots, reduction in the involvement by municipality and sector department officials, deterioration of heritage sites, lack of a proper stadium for big soccer events, inaccessibility of some tourism sites, lack of signage, marketing, lack of heritage officials in municipalities, unprotected heritage sites, vandalism, low service standards in some tourism destinations, the majority of accommodation is not graded, data collection and statistics gathering, most of the tourist guides do not have full knowledge of the entire district, there are uncoordinated tourism routes, unregistered tour guides and lack of coordination of tourism product events from local municipalities (Vhembe District Municipality, 2012).

The following areas within the district are areas in which provision of infrastructure should attract tourists (Vhembe District Municipality, 2012): Dongolo Trans-National Park, Soutpansberg Conservation, Nwanedi Nature reserve, Baobab Nature Reserve, KNP, Langjan Nature reserve, Happy Rest Nature Reserve and Honnet Nature Reserve. Middle Letaba Dam is also a "border-line" case with the northwest (left) bank being in Makhado Local Municipality and the south-east falling within Greater Giyani. Future planning of any waterside resorts or facilities would need to ensure adequate consultation and joint planning. The "Venda Heartland" is proposed as an important destination and attractions or products such as Dzata, Lake Fundudzi, Thate Vondo Forest and Phiphidi Waterfall, for example, actually lie within the three separate local municipalities of Makhado, Thulamela and Mutale. There are also rock art archaeological and historical routes.

The Limpopo Freight Databank (Limpopo Provincial Government, 2012) hosts a list of the major tourist roads and flows within the Vhembe district.

3.2 Infrastructure development

The main aim of provincial and local authorities in the region is to plan, develop, regulate, and facilitate the provision of public, freight and air transport services and infrastructure through provincial resources and co-operation with national and local authorities, as well as the private sector, in order to enhance the mobility of all communities, particularly those currently without or with limited access (Limpopo Provincial Government, 2012). The department identified the following areas in terms of needs: Giyani, Polokwane, Jane Furse, Burgersfort, Makhado, Thohoyandou and Northam. Public transport infrastructure is in high demand throughout the province. Current infrastructure is old, not integrated and not user friendly and relatively far from passengers. Particularly switching from one mode to the other, where passengers take longer time, the present infrastructure does not encourage long operational hours, thereby limiting business hours. It is commonly managed by operators and prone to bias and conflicts. Rural areas are hardest hit on this challenge. The chief directorate have prioritised main economic centres in all districts for development of intermodal facilities to respond to this (Limpopo Provincial Government, 2012).

In terms of freight, the present road infrastructure is inadequate to carry the heavy loads (Limpopo Provincial Government, 2012). There is a need to transfer some freight to rail or air. Traffic congestion delays freight transportation and some commodities lose value along the way. The issue of infrastructure is also linked to the entire transport system which should be complementary and provide modal choice and preference, hence the need for rail development as well.

The future operational capacity of road freight transport in the region is largely unlimited, over most of the road network for the foreseeable future (Limpopo Provincial Government, 2012). There are, however, specific areas of infrastructure under-capacity around the major urban and industrial areas that are in need of urgent upgrading as described in the infrastructure chapter of this report.

Investigating the required lane additions going forward, the following additional lanes are required in the following areas of the Limpopo Province (the date by which these lanes will be required is indicated in brackets):

- N1 Section between Makhado and N1/R525 junction (2005),
- R37 Section between Polokwane and Lebowakgomo (2005),
- R524 Section between Makhado and Thohoyandou - at R523 junction (2005),
- R510 Section between Limpopo/North West Province border and R572 junction (2030),
- N1 Section between R36 junction and Makhado (2030),
- N1 Section between Makhado and R525 junction and at Musina (2030),
- R71 Section between Moria and Tzaneen (2030),
- R37 between Lebowakgomo and Burgersfort (2030),
- N11 Section through Mokopane and at R516 IC (2030),
- R523 Section between R521 and R524 (2050),
- Balance of R524 Section between Makhado and Thohoyandou (2050),
- Local Sections of R36 (Tzaneen), R71 (Phalaborwa) and the R81 (Giyani) (2050),
- R525 Section in Sekhukhune (2050),
- R33 Section between N1 and Modimolle (2050),
- R101 Section between Gauteng North (Hammanskraal) and Bela-Bela (2050), and
- N1 Section between Gauteng North (Carousel Plaza) and Bela-Bela (2050).

In each of the above, one additional lane is required per direction, except for a short section of the R524 section and R523 junction, which would require the addition of two lanes by 2050 (Limpopo Provincial Government, 2012).

There is anticipation that, in future, there will be pressure on the supply of carbon based liquid fuels that are the essential power source for current road freight vehicles. The increasing cost of diesel fuel will place severe pressure on users of road haulage and, in the absence of alternative electrified rail services, the cost of long haul freight transport may severely limit industrial growth potential.

In terms of rail infrastructure, Transnet, with the current responsibility to manage capacity on the rail network, has developed a dynamic model taking into account desired market shares for the transportation of different commodities; also taking into account routing alternatives, operational alternatives, etc. to come to their own future rail capacity utilisation results. By 2030, Transnet expects the following additional bottleneck in the region: Phalaborwa – Hoedspruit. By 2050, Transnet expects the following additional bottlenecks in the Limpopo province: Musina - Louis Trichardt, Louis Trichardt – Groenbult, Modimolle - Bela-Bela, Pienaarsrivier – Hammanskraal, Hoedspruit – Kaapmuiden and Steelpoort – Belfast.

4. Climate change and transportation

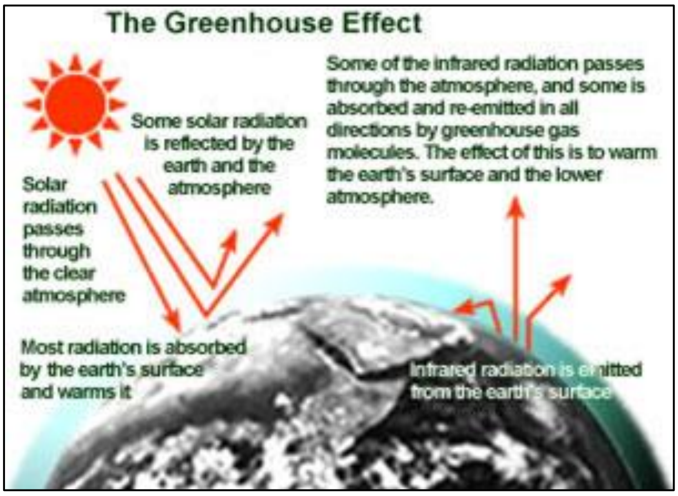
The relationship between climate change and transportation is strongly bilateral. The impacts that climate change has on transportation and its development, and the impacts that transport generates which directly affect climate change, are discussed next, in sections 4.2 and 4.3, respectively.

4.1 Brief overview of climate change

The mechanics behind the earth's climate work as follows: energy, from the sun, drives the earth's weather and climate and it heats the earth's surface; in turn, the earth radiates energy back into space. Atmospheric greenhouse gases (such as water vapour, carbon dioxide and other gases) trap some of the outgoing energy, retaining heat, somewhat like the glass panels of a greenhouse does. Without this natural "greenhouse effect" (Figure 4.1) temperatures would be much lower than they are now, and the life we know today would not be possible (US Department of Transportation, 2014).

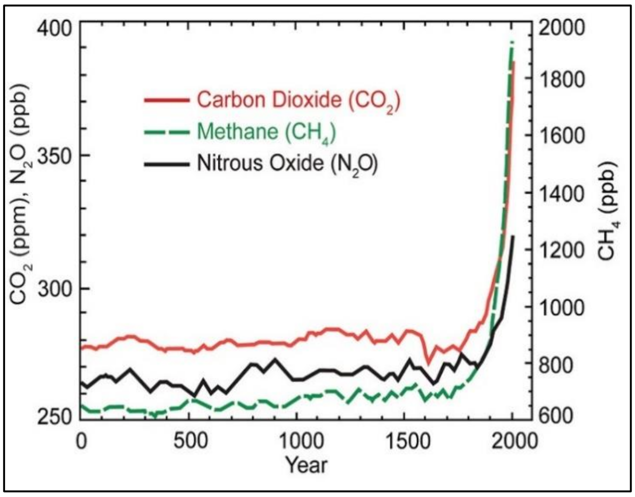
Since the beginning of the industrial revolution, atmospheric concentrations of carbon dioxide (CO2) have increased nearly 30%, methane (CH4) concentrations have more than doubled, and nitrous oxide (N2O) concentrations have risen by about 15% (Figure 4.2) These increases have enhanced the heat-trapping capability of the earth's atmosphere (US Department of Transportation, 2014).

Figure 4.3 shows the historic global temperature changes. The image on the left displays the average temperature deviations (compared to what the averages were from 1951 to 1980) between 1880 and 1889; on the right between 2000 and 2009. NASA's Goddard Institute for Space Studies (2014) found that the earth's average surface temperature has increased by about 0.7 °C (1.3 °F) since 1880. Two-thirds of the warming has occurred since 1975, at a rate of roughly 0.15 °C to 0.20 °C per decade.



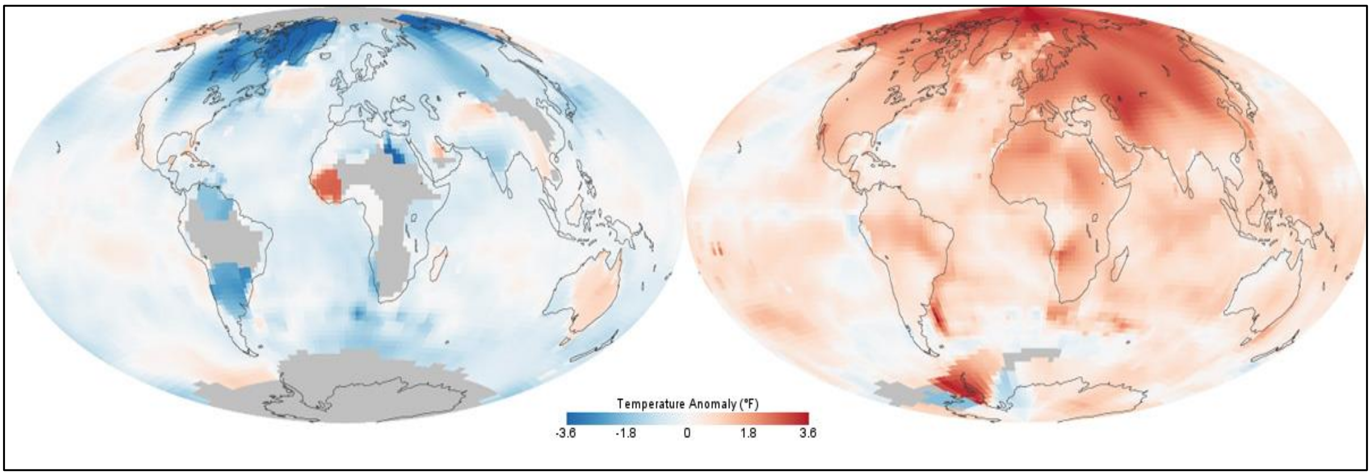
(US Department of Transportation, 2014)

Figure 4.1 The greenhouse effect



(USGCRP, 2014)

Figure 4.2 Greenhouse gas concentrations in the atmosphere over the last 2000 years



(NASA, 2014)

Figure 4.3 Comparison of global temperatures, 1880s and 1980s

Scientists generally believe that the combustion of fossil fuels and other human activities are the primary reason for the increased concentration of carbon dioxide in the earth's atmosphere. This is despite the fact that plant respiration and the decomposition of organic matter release more than ten times the CO_2 released by human activities. The latter releases have, however, always been in balance with the carbon dioxide absorbed by plant photosynthesis. What has changed in the last few hundred years is the amount of additional carbon dioxide released by human activities (US Department of Transportation, 2014). Energy burned to run cars and trucks, heat homes and businesses, and power factories is responsible for a large amount of carbon dioxide, methane and nitrous oxide emissions. Increased agriculture, deforestation, landfills, industrial production and mining also contribute a significant share of emissions globally. Carbon dioxide is typically released into the atmosphere when solid waste, fossil fuels (oil, natural gas and coal) and wood or wood products are burned. Methane, in turn, is emitted during the production and transportation of coal, natural gas, and oil. Methane emissions also result from the decomposition of organic wastes in municipal solid waste landfills, and the raising of livestock. Nitrous oxide is emitted during agricultural and industrial activities, as well as during the combustion of solid waste and fossil fuels (US Department of Transportation, 2014).

Greenhouse gas (GHG) emissions are not the only way that human interference can change the global climate. Activities, such as agriculture or road construction, can change the reflectivity of the earth's surface, leading to local warming or cooling. This effect is generally observed in urban centres, which are often warmer than surrounding, less populated areas. Emissions of small particles, known as aerosols, into the air can also lead to reflection or absorption of the sun's energy (EPA, 2014).

4.2 The impacts of climate change on transportation

4.2.1 Direct impacts of climate change

The expected direct effects of climate change include: average global temperature rise, changes in the average levels of precipitation, higher ambient levels of carbon dioxide, more frequent and severe extreme weather events, sea level rise (as a consequence of higher global temperatures) and a potential increase in the duration of the pollen season. In terms of extreme weather events, heat waves will likely be more severe, sea level rise could amplify storm surges in coastal areas, and storms will likely be more intense (USGCRP, 2009).

4.2.2 Indirect impacts of climate change

4.2.2.1 Transport activity

It is widely known that transport systems, on the whole, perform worse under adverse and extreme weather conditions. This is especially true in densely populated regions, where one single event may lead to a chain of reactions that influence large parts of the transport system. However, given the nature of transport as a derived demand, trade flow patterns will be affected by climate change in the long run when climate change affects location patterns of production and consumption (Koetse & Rietveld, 2009). Clear patterns are that precipitation affects road safety by increasing accident frequency but decreasing severity. Precipitation also increases congestion, especially during peak hours.

Regarding the production of goods and services, the sector that will probably be affected most is the agricultural sector (Koetse & Rietveld, 2009). On a global scale, especially the increase in temperature, may have a substantial impact on patterns in production and the associated patterns in trade and freight transport. Results from a broad based research project into the effects of climate change on food production on a global scale show that especially countries at higher longitudes will become more suited for food production. The climate in countries at lower longitudes, among which the majority are of developing countries, will become substantially less suited, however. This likely results in an increase in freight flows from developed to developing countries. It is difficult to quantify these effects, however.

In other economic sectors the effects of climate change will generally be smaller than in the agricultural sector, although certain patterns are clear. In moderate climate zones the demand for energy during the winter months will decline. This may, for example, lead to a decrease in demand for oil and coal in electricity production, having implications for transport of fuels (Koetse & Rietveld, 2009). In zones with higher temperatures, on the other hand, demand for electricity for cooling will increase during summer months, having the converse effect on transport volumes.

For the aviation sector, wind speeds are important because of their impacts on safety. Extreme wind speeds imply that aircrafts are not allowed to land at the designated airport and have to land at alternative airports. This has large cost implications, both for the airlines and the travellers. In a similar vein, high winds imply that the departure of aircrafts will be delayed. Wind speeds and their directions also have implications on the use of runways. Strong cross winds have an impact on the probability of accidents. Obviously, it is important for airports that sufficient runway capacity is available under various wind directions. An underestimate of wind speeds and their directions may mean that wrong decisions are taken on the design of airports in terms of the capacity and orientation of runways (Koetse & Rietveld, 2009). Periods of extreme heat may cause airplanes to face cargo restrictions, flight delays, and cancellations. However, warmer weather in winter will reduce the need for airplane de-icing (USGCRP, 2009).

Behavioural reactions to adverse weather may occur in various ways, such as trip generation, trip distribution, modal choice, route choice, temporal choice, and speed choice (Koetse & Rietveld, 2009). It is plausible that under adverse weather conditions certain trips are cancelled, that shopping occurs nearby rather than further away (distribution short run) and that average commuting distance declines (distribution long run). Regarding mode choice decisions, car drivers may, for instance, be inclined to shift to public transport when precipitation increases congestion on roads. Another possibility is that people adjust their route choice based on expectations about changes in generalised transport costs of route choice alternatives (Koetse & Rietveld, 2009). Travellers may, furthermore, change their time of departure, for example, postponing a trip until it stops raining. The last dimension of change concerns speed choice. This choice element can be considered as an instrument for car users to correct for the risk changes that occur under extreme weather conditions (Koetse & Rietveld, 2009). There is some evidence that changes in temperature, precipitation and wind affect utility attached to bicycle use (Koetse & Rietveld, 2009).

4.2.2.2 Transport infrastructure

Transportation infrastructure is designed to perform for a wide range of service lives (Table 4.1). Roads are among the shortest-lived facilities, with surfaces that must be repaved every 10 to 20 years (Transportation Research Board, 2008). Bridges, locks, and pipelines are among the longest-lived - designed for a 50- to 100-year service life - although many of their components (e.g., bridge decks) must be rehabilitated more frequently. Transportation facilities with shorter design lives provide numerous opportunities for engineers to adapt to the impacts of climate change, such as by use of more heat resistant paving materials to withstand the more extreme temperatures projected for some regions. Opportunities for adaptation (for example, elevating a bridge to accommodate expected sea level rise) are fewer for longer-lived facilities, which are rehabilitated or retrofitted at much longer intervals (Transportation Research Board, 2008).

Table 4.1 Transportation infrastructure design lives

Transportation Mode	Expected Infrastructure Design Life (years)
Highways, bridges, and tunnels	
Pavement	10–20
Bridges/culverts	50–100/30–45
Tunnels	50–100
Public transportation	
Rail track	Up to 50
Rail	
Track	Up to 50
Marine transportation	
Locks and dams	50
Docks and port terminals	40–50
Air transportation	
Runway pavements	10
Terminals	40–50
Pipeline	100

Note: Design lives are averages. Much of the infrastructure operates far beyond its design life.

(Transportation Research Board, 2008)

Due to these long lifespans, it is important to understand how future climate change might affect infrastructure investments in the coming decades. Transportation engineers typically refer to historical records of climate, especially extreme weather events, when designing transportation systems. For example, bridges are often designed to withstand storms that have a probability of occurring only once or twice every 100 years (NRC, 2008). However, due to climate change, historical climate is no longer a reliable predictor of future impacts.

Climate change is projected to concentrate rainfall into more intense storms. Heavy rains may result in flooding, which could disrupt traffic, delay construction activities, and weaken or wash out the soil and culverts that support roads, tunnels, and bridges (USGCRP, 2009; NRC, 2008). Tropical storms and hurricanes can also leave debris on railways, disrupting rail travel and freight transport (USGCRP, 2009; NRC, 2008). Damages from flooding may require rail lines and subway infrastructure to be rebuilt or raised in future expansion projects.

Exposure to flooding and extreme snow events also shortens the life expectancy of highways and roads. The stress of water and snow may cause damage, requiring more frequent maintenance, repairs, and rebuilding. Road infrastructure in coastal areas is particularly sensitive to more frequent and permanent flooding from sea level rise and storm surges (USGCRP, 2009).

More frequent and severe heat waves may require rail track repairs or speed restrictions to avoid derailments (NRC, 2008). For road transport, higher temperatures can cause pavements to soften and expand. This can create rutting and potholes, particularly in high-traffic areas, and can place stress on bridge joints. Heat waves can also limit construction activities, particularly in areas with high humidity. With these changes, it could become more costly to build and maintain roads and highways. On the other hand, certain areas may experience cost savings and improved mobility from reduced snowfall and less-frequent winter storms since warmer winters may lead to reductions in snow and ice removal, as well as salting requirements (USGCRP, 2009; NRC, 2008).

Warming temperatures and possible increases in temperature extremes will also affect airport ground facilities - runways in particular - in much the same way that they will affect roads. More heat extremes, however, are likely to be problematic. They could cause heat buckling of runways. Extreme heat can also affect aircraft lift; hotter air is less dense, reducing mass flowing over the wing to create lift. The problem is exacerbated at high-altitude airports. If runways are not sufficiently long for large aircraft to build up enough speed to generate lift, aircraft weight must be reduced or some flights cancelled altogether. Thus, increases in extreme heat are likely to result in payload restrictions, flight cancellations, and service disruptions at affected airports, and could require some airports to extend runway lengths, if feasible.

4.2.2.3 Transportation vehicles

As temperatures increase, vehicles can overheat, and tyres will deteriorate more quickly. But milder winters, reductions in the number of cold days, delays in winter freezing, and earlier spring thaws may reduce cold-weather damage to vehicles (NRC, 2008).

4.2.2.4 Water supply

Water availability

In many areas, climate change is likely to increase water demand while shrinking water supplies. This shifting balance would challenge water managers to simultaneously meet the needs of growing communities, sensitive ecosystems, farmers, ranchers, energy producers, and manufacturers.

Warmer temperatures increase the rate of evaporation of water into the atmosphere, in effect increasing the atmosphere's capacity to "hold" water (USGCRP, 2009). Increased evaporation may dry out some areas and fall as excess precipitation on other areas. Changes in the amount of rain falling during storms provide evidence that the water cycle is already changing. Over the past 50 years, the amount of rain falling during the most intense 1% of storms increased by almost 20% (USGCRP, 2009). Warming winter temperatures cause more precipitation to fall as rain rather than snow in countries that receive snow. Furthermore, rising temperatures cause snow to begin melting earlier in the year. This alters the timing of stream flow in rivers that have their sources in mountainous areas (USGCRP, 2009).

As temperatures rise, people and animals need more water to maintain their health and thrive. Many important economic activities, like producing energy at power plants, raising livestock, and growing food crops, also require water. The amount of water available for these activities may be reduced as the earth warms, and if competition for water resources increases (USGCRP, 2009). It is estimated that an 8% reduction in rainfall results in a 31% reduction in groundwater recharge and a 30% reduction in surface runoff (CSIR, 2010).

Freshwater resources along the coasts face risks from sea level rise. As the sea rises, saltwater moves into freshwater areas. This may force water managers to seek other sources of fresh water, or increase the need for desalination (or removal of salt from the water) for some coastal freshwater aquifers used as drinking water supply (USGCRP, 2009). In addition, as more freshwater is removed from rivers for human use, saltwater will move farther upstream. Water infrastructure in coastal cities, including sewer systems and wastewater treatment facilities, face risks from rising sea levels and the damaging impacts of storm surges (CCSP, 2008).

Water quality

Water quality could suffer in areas experiencing increases in rainfall. Heavy downpours can increase the amount of runoff into rivers and lakes, washing sediment, nutrients, pollutants, trash, animal waste, and other materials into water supplies, making them unusable, unsafe, or in need of water treatment (CCSP, 2008).

Drought, on the other hand, can cause coastal water resources to become more saline as freshwater supplies from rivers are reduced.

4.2.2.5 Ecosystems

Climate is an important environmental influence on ecosystems. Climate changes and the impacts of climate change affect ecosystems in a variety of ways. For instance, warming could force species to migrate to higher latitudes or higher elevations where temperatures are more conducive to their survival. Similarly, as sea level rises, saltwater intrusion into a freshwater system may force some key species to relocate or die, thus removing predators or prey that were critical in the existing food chain.

Climate change not only affects ecosystems and species directly, it also interacts with other human stressors such as development. Although some stressors cause only minor impacts when acting alone, their cumulative impact may lead to dramatic ecological changes. For instance, climate change may exacerbate the stress that land development places on fragile coastal areas. Additionally, recently logged forested areas may become vulnerable to erosion if climate change leads to increases in heavy rain storms.

For many species, the climate where they live or spend part of the year influences key stages of their annual life cycle, such as migration, blooming, and mating. Changes like these can lead to mismatches in the timing of migration, breeding, and food availability. Growth and survival are reduced when migrants arrive at a location before or after food sources are present (CCSP, 2008).

Warming air temperature can directly raise stream and lake temperatures, which can harm aquatic organisms that live in cold water habitats, such as trout. Additionally, warmer water can increase the range of non-native fish species, permitting them to move into previously cold water streams. The population of native fish species often decreases as non-native fish prey on and out-compete them for food (CCSP, 2008). Aquatic species that live in only cold water environments, such as salmon, will be affected by rising water temperatures. Changing water temperatures would, thus, also affect the geographic range of fish species (USGCRP, 2009).

Climate change, along with habitat destruction and pollution, is one of the important stressors that can contribute to species extinction. The IPCC estimates that 20% to 30% of the plant and animal species evaluated so far in climate change studies are at risk of extinction if temperatures reach levels projected to occur by the end of this century (Fischlin, et al., 2007). Projected rates of species extinctions are 10 times greater than recently observed global average rates and 10,000 times greater than rates observed in the distant past (as recorded in fossils) (Millennium Ecosystem Assessment, 2005).

Forestry

Climate influences the structure and function of forest ecosystems and plays an essential role in forest health. Carbon dioxide is required for photosynthesis, the process by which green plants use sunlight to grow. Given sufficient water and nutrients, increases in atmospheric CO_2 may enable trees to be more productive (CCSP, 2008), yielding a positive impact on the forestry sector.

A changing climate may worsen many of the threats to forests, such as pest outbreaks, fires, human development, and drought (EPA, 2014). Climate changes directly and indirectly affect the growth and productivity of forests: directly due to changes in atmospheric carbon dioxide and climate and indirectly through complex interactions in forest ecosystems. Climate also affects the frequency and severity of many forest disturbances.

Warming temperatures could increase the length of the growing season. However, warming could also shift the geographic ranges of some tree species. Habitats of some types of trees are likely to move northward or to higher altitudes. Other species may be at risk locally or regionally if conditions in their current geographic range are no longer suitable (CCSP, 2008). For example, species that currently exist only on mountaintops in some regions may die out as the climate warms, since they cannot shift to a higher altitude.

Climate change will likely increase the risk of drought in some areas and the risk of extreme precipitation and flooding in others. Although many trees are resilient to some degree of drought, increases in temperature could make future droughts more damaging than those experienced in the past. In addition, drought increases wildfire risk, since dry trees and shrubs provide fuel to fires. Drought also reduces trees' ability to produce sap, which protects them from destructive insects such as pine beetles (USGCRP, 2009).

Climate change could also alter the frequency and intensity of forest disturbances such as insect outbreaks, invasive species, wildfires, and storms. Rising temperatures may enable some insect species to develop faster and expand their ranges. These disturbances can reduce forest productivity and change the distribution of tree species. In some cases, forests can recover from a disturbance. In other cases, existing species may shift their range or die out. In these cases, the new species of vegetation that colonize the area create a new type of forest. Invasive plant species can displace important native vegetation because the invasive species often lack natural predators. Climate change could benefit invasive plants, since they are generally more tolerant to a wider range of environmental conditions than are native plants (USGCRP, 2009).

Disturbances can interact with one another, or with changes in temperature and precipitation, to increase risks to forests. For example, drought can weaken trees and make a forest more susceptible to wildfire or insect outbreaks. Similarly, wildfire can make a forest more vulnerable to pests (CCSP, 2008; USGCRP, 2009).

Forestry is one of the main economic activities in the Letaba region – changes in forestry will directly influence the volume of freight transportation on the road network.

4.2.2.6 Agriculture

Agriculture and fisheries are highly dependent on specific climate conditions. Trying to understand the overall effect of climate change on our food supply can be difficult. Increases in temperature and carbon dioxide can be beneficial for some crops in some places. But to realise these benefits, nutrient levels, soil moisture, water availability, and other conditions must also be met (EPA, 2014).

Changes in the success of agricultural endeavours proportionally affect the volume of freight to be moved in areas where agriculture is one of the main drivers of transport demand (as in the Letaba district). This is especially true for crop farming and, to a lesser extent, for livestock rearing.

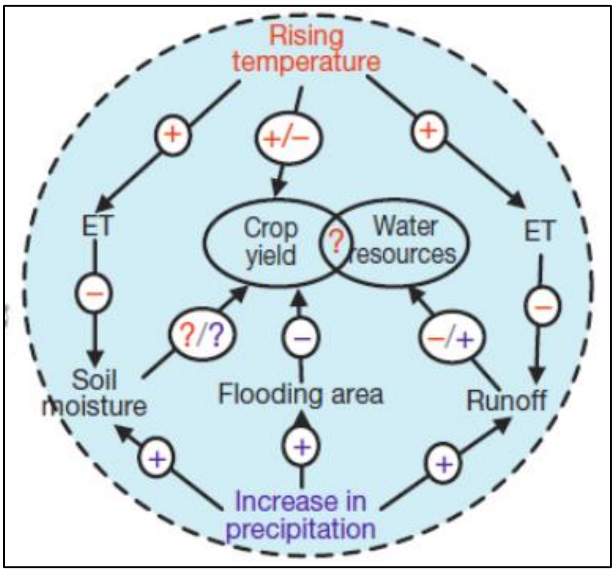
Crop yields

Changes in temperature, amount of carbon dioxide (CO_2), and the frequency and intensity of extreme weather could have significant impacts on crop yields. Warmer temperatures may make many crops grow more quickly, but warmer temperatures could also reduce yields. Crops tend to grow faster in warmer conditions. However, for some crops (such as grains), faster growth reduces the amount of time that seeds have to grow and mature (USGCRP, 2009). This can reduce yields (i.e., the amount of crop produced from a given amount of land). For any particular crop, the effect of increased temperature will depend on the crop's optimal temperature for growth and reproduction. In some areas, warming may benefit the types of crops that are typically planted there. However, if warming exceeds a crop's optimum temperature, yields can decline.

Higher CO_2 levels can increase yields. The yields for some crops, like wheat and soybeans, could increase by 30% or more under a doubling of CO_2 concentrations. The yields for other crops, such as corn, exhibit a much smaller response (less than 10% increase) (CCSP, 2008).

More extreme temperature and precipitation can prevent crops from growing. Extreme events, especially floods and droughts, can harm crops and reduce yields. Many weeds, pests and fungi thrive under warmer temperatures, wetter climates, and increased CO_2 levels. Moreover, increased use of pesticides and fungicides may negatively affect human health (USGCRP, 2009).

Figure 4.4 shows the impacts on the climate change impacts of rising temperatures and increased precipitation on crop yields. ET stands for evaporation.



(Piao, et al., 2010)

Figure 4.4 Impacts of climate change on crop yield

Livestock management

Heat waves, which are projected to increase under climate change, could directly threaten livestock. Heat stress affects animals both directly and indirectly. Over time, heat stress can increase vulnerability to disease, reduce fertility, and reduce milk production.

Drought may threaten pasture and feed supplies. Drought reduces the amount of quality forage available to grazing livestock. Some areas could experience longer, more intense droughts, resulting from higher summer temperatures and reduced precipitation. For animals that rely on grain, changes in crop production, due to drought, could also become a problem.

Climate change may increase the prevalence of parasites and diseases that affect livestock. The earlier onset of spring and warmer winters could allow some parasites and pathogens to survive more easily. In areas with increased rainfall, moisture-reliant pathogens could thrive (CCSP, 2008)

Increases in carbon dioxide may increase the productivity of pastures, but may also decrease their quality. Increases in atmospheric CO_2 can increase the productivity of plants on which livestock feed. However, studies indicate that the quality of some of the forage found in pasturelands decreases with higher CO_2. As a result, cattle would need to eat more to get the same nutritional benefits (EPA, 2014).

4.2.2.7 Human health

Weather and climate play a significant role in people's health. Changes in climate affect the average weather conditions that we are accustomed to. Warmer average temperatures will likely lead to hotter days and more frequent and longer heat waves. This could increase the number of heat-related illnesses and deaths (EPA, 2014). Increases in the frequency or severity of extreme weather events such as storms could increase the risk of dangerous flooding, high winds, and other direct threats to people and property. Warmer temperatures could increase the concentrations of unhealthy air and water pollutants. Changes in temperature, precipitation patterns, and extreme events could enhance the spread of some diseases.

The impacts of climate change on health will depend on many factors. These factors include the effectiveness of a community's public health and safety systems to address or prepare for the risk and the behaviour, age, gender, and economic status of individuals affected. Impacts will likely vary by region, the sensitivity of populations, the extent and length of exposure to climate change impacts, and society's ability to adapt to change. Many of the expected health effects are likely to fall mostly on the poor, the very old, the very young, the disabled, and the uninsured (USGCRP, 2009).

Heat waves, specifically, can lead to heat stroke and dehydration, and are the most common cause of weather-related deaths (CCSP, 2008; USGCRP, 2009).

Urban areas are typically warmer than their rural surroundings. Climate change could lead to even warmer temperatures in cities. This would increase the demand for electricity in the summer to run air conditioning, which, in turn, would increase air pollution and greenhouse gas emissions from power plants.

Extreme weather events can: reduce the availability of fresh food and water, interrupt communication, utility, and health care services, contribute to carbon monoxide poisoning from portable electric generators used during and after storms, increase stomach and intestinal illness among evacuees and contribute to mental health impacts such as depression and post-traumatic stress disorder (PTSD) (CCSP, 2008; USGCRP, 2009).

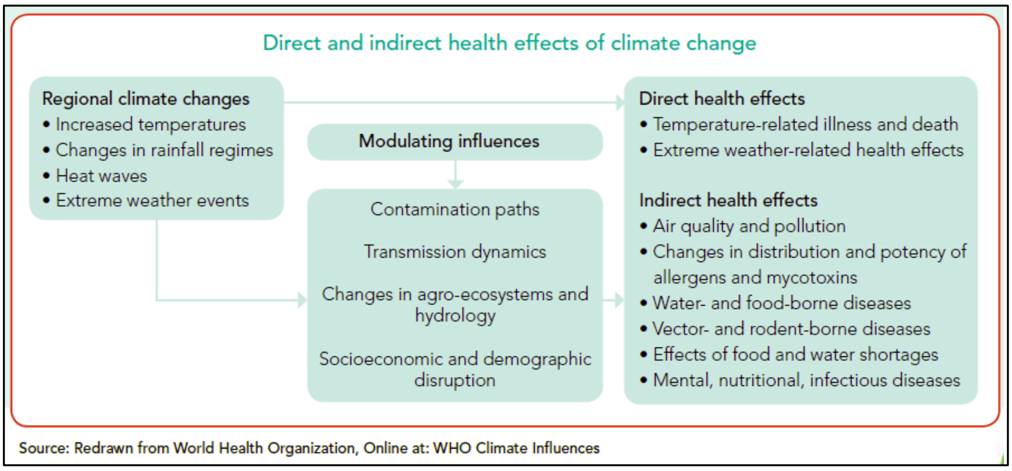
Scientists project that warmer temperatures from climate change will increase the frequency of days with unhealthy levels of ground-level ozone, a harmful air pollutant, and a component in smog (CCSP, 2008). Ground-level ozone can damage lung tissue and can reduce lung function and inflame airways. This can increase respiratory symptoms and aggravate asthma or other lung diseases. It is especially harmful to children, older adults, outdoor workers, and those with asthma and other chronic lung diseases.

Climate change may affect allergies and respiratory health. The timing and duration of the pollen may change (EPA, 2014).

Changes in climate may enhance the spread of some diseases (USGCRP, 2009). Disease-causing agents, called pathogens, can be transmitted through food, water, and animals such as deer, birds, mice, and insects. Climate change could affect all of these transmitters. Higher air temperatures can increase cases of salmonella and other bacteria-related food poisoning because bacteria grow more rapidly in warm environments. These diseases can cause gastrointestinal distress and, in severe cases, death. Heavy rainfall or flooding, in turn, can increase water-borne parasites such as Cryptosporidium and Giardia that are sometimes found in drinking water (USGCRP, 2009). These parasites can cause gastrointestinal distress and, in severe cases, death.

Heavy rainfall events cause storm water runoff that may contaminate water bodies used for recreation (such as lakes and beaches) with other bacteria. The most common illness contracted from contamination at beaches is gastroenteritis, an inflammation of the stomach and the intestines that can cause symptoms such as vomiting, headaches, and fever. Other minor illnesses include ear, eye, nose, and throat infections (CCSP, 2008).

The CSIR (2010) summarised the impacts of climate change on human health in Figure 4.5.



(CSIR, 2010)

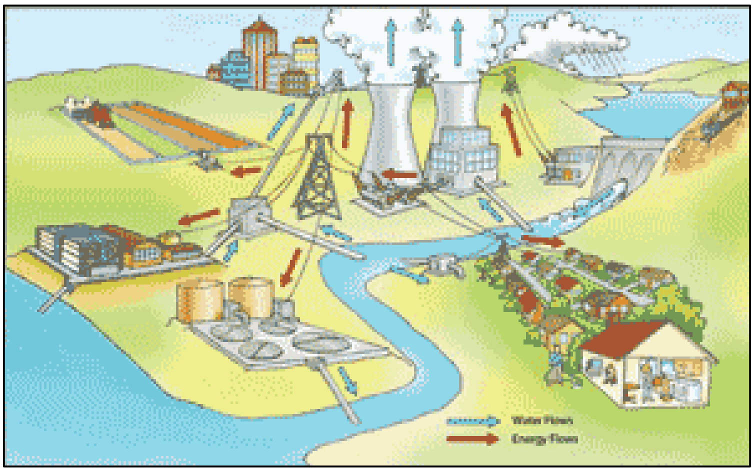
Figure 4.5 Direct and indirect health effects of climate change

4.2.2.8 Energy sector

Increases in temperature will likely change how much energy we consume, as well as our ability to produce electricity and deliver it reliably (EPA, 2014).

Figure 4.6 illustrates the water and energy flows in a community with a dam, power plant and housing. Energy is needed to pump, transport, and treat drinking water and wastewater. Cooling water is needed to run many of today's power plants.

A warmer climate may reduce the efficiency of power production for many existing fossil fuel and nuclear power plants because these plants use water for cooling. The colder the water, the more efficient the generator. Thus, higher air and water temperatures could reduce the efficiency with which these plants convert fuel into electricity (USGCRP, 2009). Power plants can require large amounts of water for cooling. A few power plants rely mainly on air for cooling, but that technology is often more expensive and uses more energy than water-cooled plants.



(EPA, 2014)

Figure 4.6 Energy and water links

Water is also used to produce energy through hydropower. If climate change results in lower stream flows in areas where hydropower is generated, it will reduce the amount of energy that can be produced. Changes in the timing of stream flow can also have an impact on the ability to produce hydroelectricity (EPA, 2014). Lower water flows would also reduce the amount of water available to cool fossil-fuel and nuclear power plants.

Growing crops for biomass and biofuel energy could stress water resources in certain regions, depending on the type of crop, where it is grown, agricultural production in the region, and current water and nutrient management practices.

Climate change could impact wind and solar power, but there is little research in this area. Impacts will depend on how wind and cloud cover patterns change, which are very difficult to project using current climate models (EPA, 2014).

A large portion of energy infrastructure is typically located in coastal areas and, therefore, sensitive to sea level rise and storm surge. For example, fuel ports and the generation and transmission lines that bring electricity to major urban coastal centres are at risk. Changes in the frequency and severity of storms and other extreme events may also damage energy infrastructure. Flooding and intense storms can damage power lines and electricity distribution equipment. These events may also delay repair and maintenance work. Electricity outages can have serious impacts on other energy systems as well. For example, oil and gas pipeline disruptions following extreme weather events are often caused by power outages rather than physical damage to the infrastructure (EPA, 2014).

4.2.2.9 Societal impacts

Projected climate change will affect certain groups of people more than others, depending on where they live and their ability to cope with different climate hazards. In some cases, the impacts of climate change would worsen existing vulnerabilities (EPA, 2014). People who live in poverty may have a difficult time coping with changes. These people have limited financial resources to cope with heat, relocate or evacuate or respond to increases in the cost of food (USGCRP, 2009; CCSP, 2008). Older adults may be among the least able to cope with impacts of climate change. Similarly, young children are another sensitive age group, since their immune system and other bodily systems are still developing and they rely on others to care for them in disaster situations (CCSP, 2008).

Although climate change is an inherently global issue, the impacts will not be felt equally across the planet (EPA, 2014). Impacts are likely to differ in both magnitude and rate of change in different continents, countries, and regions. Some nations will likely experience more adverse effects than others. Other nations may benefit from climate changes. The capacity to adapt to climate change can influence how climate change affects individuals, communities, countries, and the global population.

Climate change impacts will also differ according to gender. Women in developing countries are especially vulnerable. The ratio of women (to the total population) affected or killed by climate-related disasters is already higher in some developing countries than in developed countries (EPA, 2014).

Certain areas benefit from being located close to natural resources that support the local economy. Climate change could threaten these resources, as well as the goods and services they produce and the jobs and livelihoods of those who depend upon them (USGCRP, 2009). For example, climate change will likely affect farming communities, tourism and recreation, and the insurance industry. Communities that developed around the production of different agricultural crops, such as corn, wheat, or cotton, depend on the climate to support their way of life.

Climate change will also likely affect tourism and recreational activities. An increasing number of wildfires could affect hiking and recreation in parks. Beaches could suffer erosion due to sea level rise and storm surge. Changes in the migration patterns of fish and animals would affect fishing and hunting. Communities that support themselves through these recreational activities would feel economic impacts as tourism patterns begin to change (USGCRP, 2009).

Climate change may make it harder and more expensive for many people to insure their homes, businesses, or other valuable assets in risk-prone areas. Insurance is one of the primary mechanisms used to protect people against weather-related disasters (USGCRP, 2009). We rely on insurance to protect investments in real estate, agriculture, transportation, and utility infrastructure by distributing costs across society. Climate change is projected to increase the frequency and intensity of extreme weather events, such as heat waves, droughts, and floods. These changes are likely to increase losses to property and cause costly disruptions to society. Escalating losses have already affected the availability and affordability of insurance. More frequent losses, increased variability in the type and location of impacts, and increases in widespread losses that occur at the same time would increase the risks to insurers and their customers (USGCRP, 2009).

4.2.3 Summary of the overall impacts of climate change

Figure 4.7 graphically displays the links between climate change, the environment, drivers of transportation and transportation itself.

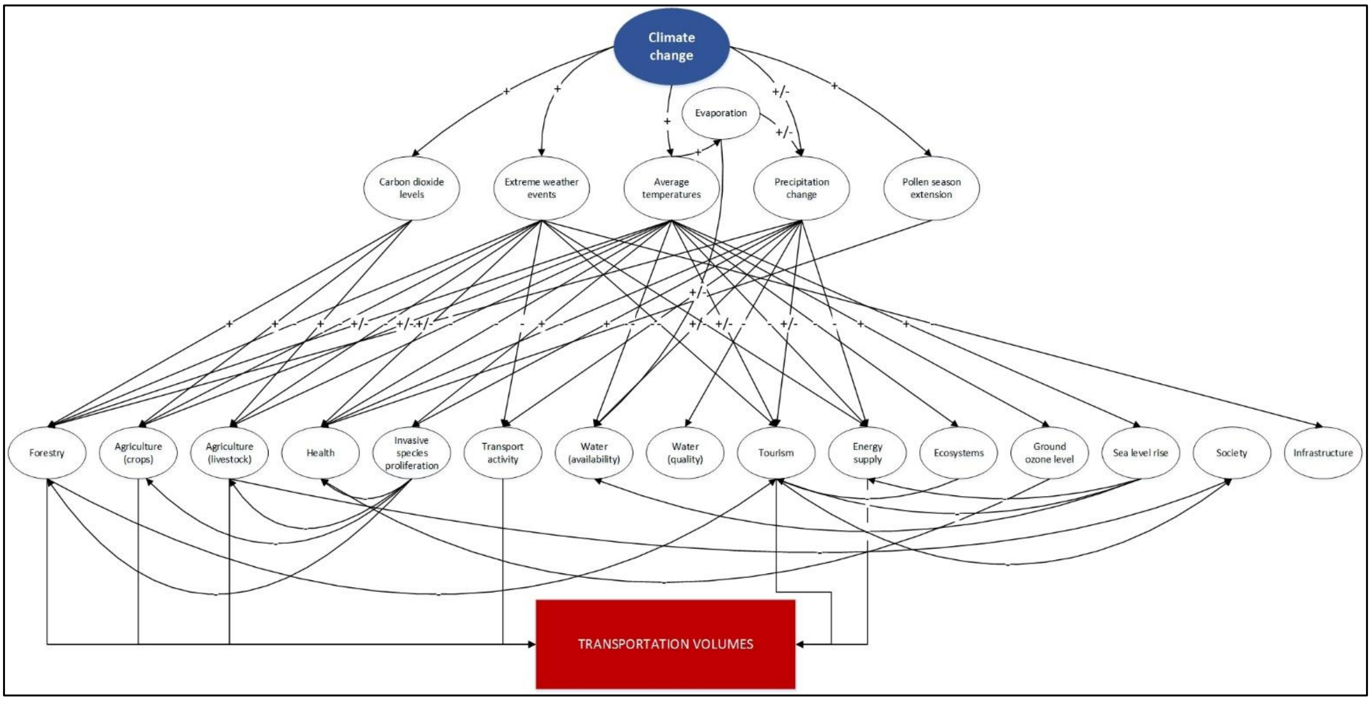


Figure 4.7 Direct and indirect impacts of climate change

4.3 The impact of transportation on climate change

Primarily, the greenhouse gases emitted during transportation activities contribute to climate change. For a more in-depth look at the influence of transportation on climate change, please refer to sections 5 (in general), 5.3 and 5.14 (specifically).

4.4 The linkages between climate change and transportation in the Letaba catchment

4.4.1 Climate change impacts on Africa in general

Africa is one of the most vulnerable continents to climate variability and change, because of multiple existing stresses and low adaptive capacity (EPA, 2014). Existing stresses include poverty, political conflicts, and ecosystem degradation. By 2050, between 350 million and 600 million people are projected to experience increased water stress due to climate change (EPA, 2014).

Climate variability and change is projected to severely compromise agricultural production, including access to food, in many African countries and regions. Toward the end of the 21st century, projected sea level rise will likely affect low-lying coastal areas with large populations.

Climate variability and change can negatively impact human health, as previously discussed. In many African countries, other factors already threaten human health (EPA, 2014). For example, malaria threatens health in Southern Africa and the East African highlands. The compound effect can be devastating for African nations.

4.4.2 The South African GHG inventory for transport activity

Table 4.2 shows the official South African GHG inventory data for transportation (Mwakasonda, et al., 2009). The dominance of road transportation in the country is evident when the total energy consumption is observed relative to all other transportation modes. The emissions intensity of road gasoline surpasses that of all other mode and fuel combinations.

Table 4.2 South African transport activity and emissions data

Transport	Amount (TJ)	Emission factors (kg/TJ)		
		CO_2	CH_4	N_20
Av jet kerosene	27 097	0.5	2	71 500
Av other kerosene	245	0.5	2	71 500
Av gas	835	0.5	2	69 300
Av gas works gas	29	0.5	2	69 300
Road LPG	53	62	0.2	63 100
Road gasoline	352 259	33	3.2	69 300
Other gasoline from SAPIA difference)	302	3	0.6	69 300
Road Gas works	29	1	0.1	69 300
Road gas/diesel	155 058	3.9	1.3	74 300
Rail gas/diesel	8 282	4.15	28.6	74 100
Other gas/diesel from SAPIA difference	910	3	0.6	74 100
Total	**544 193**			
International bunkers				
Marine gas/diesel	13 228	7	2	74 100
Marine RFO	100 249	7	2	77 400
Av jet kerosene	40 646	0.5	2	71 500
Total	**154 125**			

(Mwakasonda, et al., 2009)

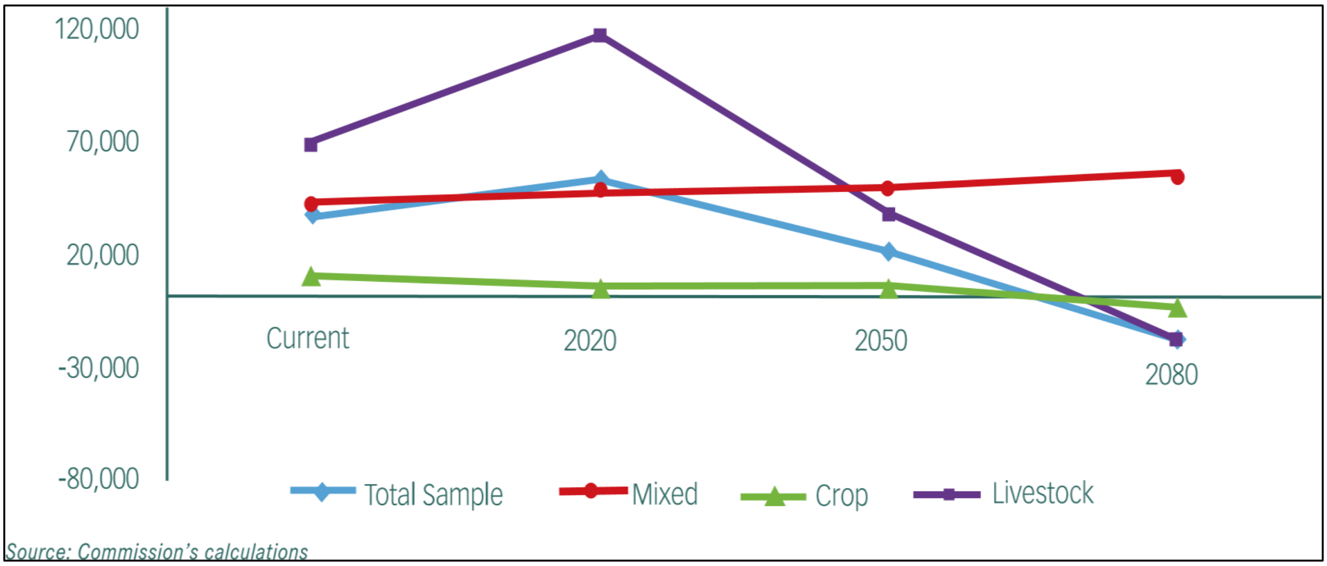
4.4.3 Climate change impacts on South Africa

In South Africa, climate change is expected to result in higher temperatures, more sporadic rainfall patterns and frequent droughts (Financial and Fiscal Commission, 2012). Superimposed on the country's already scarce water resources, these impacts are expected to affect all sectors of the economy. South Africa is particularly vulnerable to climate change because of its dependence on climate-sensitive economic sectors, high levels of poverty and the inter-related impacts of HIV/AIDS (Financial and Fiscal Commission, 2012). The poor are disproportionately affected, as they rely on sectors that will be directly affected by climate change: agriculture, biodiversity, ecosystems and water supplies.

Agriculture is highly dependent on climate and, therefore, particularly vulnerable. Climate change will have a significant impact on low-input farming systems in developing countries in Africa. Smallholder farmers are expected to be more vulnerable, as they lack the means for adaptation. The effect of climate change on agricultural output will directly affect rural communities, through reduced income and employment, and knock-on effects for rural economies as a whole. The result will be to put considerable strain on rural local governments, which provide services and promote development at a local level. Local municipalities need to plan for the negative impacts of climate change, as their burden will grow because of the expected increase in natural disasters, water scarcity, reduced agricultural production and food security, and diseases (Financial and Fiscal Commission, 2012).

4.4.3.1 Agriculture in South Africa

Two types of farmers exist in South Africa: subsistence farming households that supplement their income and food requirements through agriculture, and commercial farmers that generate revenue through farming (i.e. the farm is a business entity). In general, a study performed by the Financial and Fiscal Commission (2012) shows that a simultaneous decrease in rainfall and increase in temperature adversely affects both subsistence farmers (151% loss in net revenue by 2080) and commercial farmers (111% loss in net revenue by 2080). The results show that by 2080 commercial farmers are likely to lose a total of R694 billion rand as a result of climate change. The effects will be more severe among crop farmers, while mixed farmers are least vulnerable to climate change (Figure 4.8). By 2080, climate change will result in subsistence crop and commercial crop farmers losing approximately 144% of their net revenue, and commercial livestock and subsistence livestock farmers losing 127%. For horticultural farmers, losses of 86% in net revenues are expected for both subsistence and commercial farmers, while commercial farmers practising mixed farming methods face losses of 71%. Subsistence mixed farmers are the only type of farmer who stands to benefit somewhat from the predicted climate changes in the longer run, with increases in net revenue of 30% predicted for 2080.

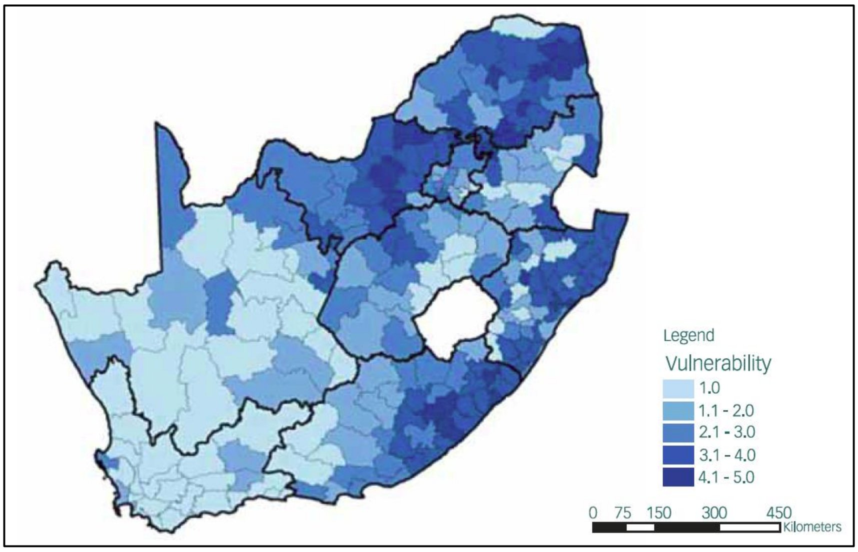


(Financial and Fiscal Commission, 2012)

Figure 4.8 Predicted change in net revenue for subsistence farmers as a result of decreased rainfall and increased temperatures (Rands)

Subsistence farmers use a large proportion (57.8%) of the output from crop agriculture to feed their households and sell only 30.1% to generate revenue that supplements the household's income (Financial and Fiscal Commission, 2012). Among livestock farmers, a relatively larger proportion (48.9%) of livestock output is sold to generate revenue, rather than kept to feed the household (26.7%) or used for other purposes. The most severely affected provinces will be North West and Limpopo. These provinces already contain arid areas and, so, further increases in temperature and decreases in rainfall are likely to make them even drier and, hence, less productive. Linking these provincial findings for climate-change impacts on commercial farming to municipal areas, two provinces – Limpopo and North West again – contain 11 of the most vulnerable municipalities identified (Financial and Fiscal Commission, 2012).

As the impacts of climate change will be localised, local institutions and governance will be the most important drivers of adaptation and coping mechanisms. Vulnerability is a measure of susceptibility to damage or harm. Although the vulnerability of various socio-ecological systems and stressors is assessed, the focus here is on vulnerability to climate change. The Intergovernmental Panel on Climate Change (IPCC) uses a conceptual structure in which vulnerability is characterised as a function of exposure and sensitivity to stress, on the one hand, and capacity to deal with the effects of the stress on the other. Exposure in the north-east of South Africa is largely because of changes in temperature, rainfall and increased exposure to malaria. An overview of the various vulnerability ratings for South African municipal districts is provided in Figure 4.9. From this picture, one can see that the study area is classified as extremely vulnerable.



(Financial and Fiscal Commission, 2012)

Figure 4.9 Index value of vulnerability to climate change for South African municipalities

In total, twenty municipalities were classed as highly vulnerable (Table 4.3). As a group, rural municipalities (type B4) were significantly more vulnerable than other non-metro municipalities. Greater Giyani, Greater Letaba and Thulamela are amongst the top twenty.

Table 4.3 Twenty most vulnerable municipalities in South Africa

Municipality Name	Municipality Code	Municipality Type	Municipality Name	Municipality Code	Municipality Type
Mnquma	EC122	B4	Thulamela	LIM343	B4
Intsika Yethu	EC135	B4	Aganang	LIM352	B4
Engcobo	EC137	B4	Ephraim Mogale	LIM471	B4
Port St Johns	EC154	B4	Elias Motsoaledi	LIM472	B4
Ntabankulu	EC444	B4	Fetakgomo	LIM474	B4
Indaka	KZN233	B4	Thembisile	MP315	B4
Mandeni	KZN291	B4	Moretele	NW371	B4
Maphumulo	KZN294	B4	Moses Kotane	NW375	B4
Greater Giyani	LIM331	B4	Ditsobotla	NW384	B3
Greater Letaba	LIM332	B4	City of Matlosana	NW403	B1

(Financial and Fiscal Commission, 2012)

4.4.4 Climate impacts on the north eastern part of South Africa

The CSIR (2010) published future (up to 2050) climate change projections for the north eastern part of South Africa (which contains the study area). An overview of the projected impacts is provided in this section.

4.4.4.1 Temperature changes

Maximum temperature change: an increase in annual maximum day temperature of approximately 0.5°C is expected. A decrease of between 0.27°C and 1.26°C is possible for April, May, June, and July.

Mean temperature change: an increase in annual mean day temperature of between 0°C and 0.89°C is expected. Spring (September-October-November) shows the greatest change in mean day temperature, with an average increase of 1.28°C expected over the three months.

Minimum temperature change: an increase of between 0.6°C and 1.16°C in the minimum day temperature for all months of the year, with no regions experiencing below zero temperatures, is to be expected (CSIR, 2010).

4.4.4.2 Changes in rainfall

An increase in total annual rainfall is expected for the whole region, with possible distinct increases along the escarpment. An extension of the rain season may occur into early spring, due to the increase in rainfall predicted for September-October-November. Autumn and winter are also expected to receive more rainfall and this may have significant consequences for biological triggers and cropping calendars.

Rainfall is expected to increase by between 85 mm and 303 mm per year for the region as a whole. The greatest increase in rainfall is expected during February, April and September with increases of above 30 mm, according to the upper limit of change predicted. There are, however, a range of possibilities where rainfall could decrease during some months (CSIR, 2010).

4.4.4.3 Changes in evaporation

Despite the increase in mean annual rainfall, future evaporation is expected to increase. This means that there will likely be less water available for use in the future (CSIR, 2010).

4.4.4.4 Dry-spell duration

The numbers of dry days per year are expected to decrease, due to the future increase in mean annual rainfall. The greatest change in the number of dry days is projected for June, whereas there is little change expected for the summer and spring months (September to January). There is little to no change in the dry-spell duration in spring and summer. For the region in general, the dry-spell duration is expected to decrease in autumn by between half a day and three days, and in winter by between one and 6.7 days. This corresponds with the increase in rainfall expected during these seasons (CSIR, 2010).

4.4.4.5 Frequency of rainfall events

The number of rain events is expected to increase (CSIR, 2010). This could infer that the chances of floods may increase. The majority of rain events are expected to occur in November, December and January, which have the highest number of days experiencing rainfall. The number of rain days per month is expected to increase by between 1 and 2.2 days. This small change in the number of rain days per month compared with the increase in rainfall demonstrates that the intensity of rain events and, possibly, the severity of rain events may increase. The lower limit of change shows a decrease in the number of rain days for the majority of the year; this may also be a likely possibility.

4.4.4.6 Indirect impacts in the region

Agriculture is expected to be negatively impacted in the region, as a result of expected climate change. With regards to changes in conservation and tourism, several studies indicate that the majority of endemic species are likely to show contractions of geographic range, and that up to 30% of endemic species may be at increasingly high risk of extinction in the country. One specific study shows a significant range contraction in almost 80% of the 179 species (including 34 bird, 19 mammal, 50 reptile, 15 butterfly and 57 other invertebrate species) included in the research. The majority of these range contractions are expected to occur in the eastern half of South Africa.

Rising atmospheric CO_2 levels may be increasing the cover of shrubs and trees in grassland and savannah biomes, with mixed effects on biodiversity, and possible positive implications for carbon sequestration. For example, Colophospermum mopane woodlands are known to have a low density of herbivores due to the low grass biomass and the high density of the trees, which increases ungulates' susceptibility to predation. An expansion of C. mopane will have strong negative impacts on the tourism experience through potentially reduced numbers of game within these patches, resulting in reduced game viewing opportunities.

It is significant that agriculture has been identified as the sector through which a number of the local municipalities in Mpumalanga and Limpopo decided to focus future economic development. The predicted changes in climate, however, could force the shutdown or relocation of agricultural business in vulnerable areas, which would have an enormous effect on economic development of the area, as well as on a community which is made up largely of unskilled labour.

4.4.4.7 Summary of projected climate change impacts in the study region

In summary, temperatures are expected to increase along with precipitation and evaporation levels in the study area, according to the CSIR projections. There will be shorter dry spells and an increased number of rainfall days. This will negatively impact tourism and agriculture in the region, but might be a boon to the forestry industry.

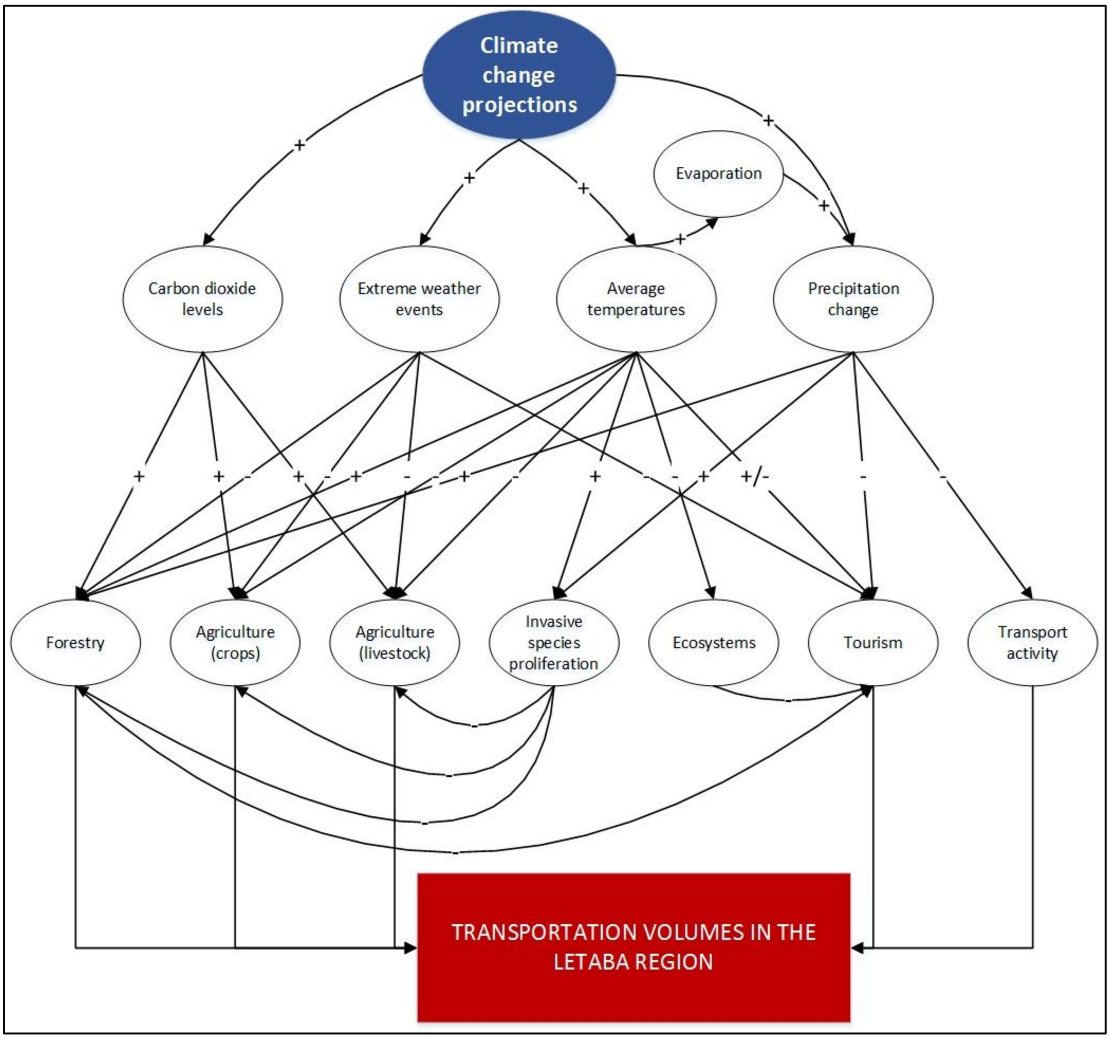


Figure 4.10 Expected climate change impacts in the study area, based on the CSIR projections

5. Environmental impacts of transportation

Identifying major transportation activities with impacts on natural resources is an essential first step in effective environmental management (Rondinelli & Berry, 2000). Three sets of activities associated with transportation - vehicle operations, equipment maintenance and facilities operations - can have negative impacts on the environment. In addition, transportation infrastructure construction and expansion often generate pollutants or endanger natural resources (Rondinelli & Berry, 2000). An indirect cause of environmental impacts associated with transportation activity is the generation, storage and supply of the energy used to power the sector.

Air pollution is, generally, considered to be the most important environmental threat posed by transportation. There are two main types of air pollution: the first is the emission of gases which affect air quality and the second is gases, termed greenhouse gases (GHGs), which affect the earth's climate (see also section 4.1). Trace quantities of certain additional pollutants are emitted by transportation. These include benzene (a known carcinogen), toluene, polynuclear aromatic hydrocarbons, formaldehyde, cyanide, hydrogen sulphide and dioxin, amongst others. There is very little information available on these pollutants, as they are not regulated, nor are their impacts completely understood (OECD, 1997) and, thus, they are excluded from further analysis.

Transportation activities also generate soil, ground water, and surface water contaminants. The major sources of said contaminants are: petroleum product disposal, sulphuric acid from battery leaks and disposal, organic hazardous air pollution (HAP) emissions, water and soil pollution from waste solvents, cleaning and de-icing fluids, fuel spillage, degreasers, coolant releases, and solid and liquid wastes from terminal operations (Rondinelli & Berry, 2000).

This section (section 5) provides more information on the different environmental impacts generated by transportation, their effects on the planet or society and the components of transportation provision where they originate.

5.1 Air pollution

5.1.1 Various types of air pollutants

5.1.1.1 Carbon monoxide (CO)

Carbon monoxide is a product of the incomplete combustion of carbon fuels (Dalkmann, Sakamoto, & al., 2011; Gilbert & Perl, 2008; Central European University, 2002). It is highly toxic and difficult to perceive with human senses, as it is odourless and colourless. The main source of CO is gasoline engines; diesel engines produce much smaller quantities of these pollutants (Central European University, 2002).

Carbon monoxide interferes with the uptake of oxygen in the blood by binding to the blood haemoglobin and it also has negative impacts on the heart, on circulation, and on the nervous system (Central European University, 2002). High concentrations are lethal (Gilbert & Perl, 2008).

5.1.1.2 Hydrocarbons (HC)

Hydrocarbons are unburned fuel vapours and can include several hundreds of organic substances created during the incomplete combustion of fossil fuels. The most important hydrocarbons are benzene and ethylene. Hydrocarbons react in the presence of nitrogen oxides and sunlight to form ground-level ozone, a major component of photochemical smog (Central European University, 2002). A number of exhaust hydrocarbons are also toxic, with the potential to cause cancer.

5.1.1.3 Nitrous oxides (NO_x)

Nitric oxide (NO) is the major gas released during fuel combustion under high temperatures and pressure, typical of the internal combustion engine (Central European University, 2002). This gas, when released in the atmosphere, is usually quickly oxidised into nitrogen dioxide (NO_2). Even though it is typically produced in low quantities, relatively low concentrations can generate serious health concerns (Dalkmann, Sakamoto, & al., 2011). Nitrous oxides are harmful to organisms, contribute to acid rain (along with sulphur dioxide) and constitute an ingredient in the formulation of ozone (when reacting with hydrocarbons) (Central European University, 2002).

5.1.1.4 Particulate matter (PM)

Particulate matters include many different substances that have different origins. The common characteristic is that they all contain a carbon nucleus and various other components (hydrocarbons, inorganic sulphates and nitrates, as well as metals and polycyclic aromatic hydrocarbons) adsorbed on it (Central European University, 2002).

One of these pollutants is composed by small particles suspended in the air, a product of combustion (mainly from diesel engines) (Dalkmann, Sakamoto, & al., 2011; Gilbert & Perl, 2008). Soot is impure carbon particles resulting from the incomplete combustion of hydrocarbons. The key impact of soot is its contribution to respiratory and heart diseases (Gilbert & Perl, 2008).

Soot is a powder-like form of amorphous carbon and contains black carbon (BC) and organic aerosols. Chemically, black carbon is a component of fine particulate matter ($PM \leq 2.5$ µm in aerodynamic diameter). The two main impacts of black carbon emissions are health related risks and climate change contributions. Black carbon is a climate forcing agent. Black carbon warms the earth by absorbing heat in the atmosphere and by reducing albedo, the ability to reflect sunlight, when deposited on snow and ice. Black carbon stays in the atmosphere for only several days to weeks, whereas carbon dioxide (CO_2) has an atmospheric lifetime of more than 100 years (Ramanathan & Carmichael, 2008).

Humans are exposed to black carbon by inhalation of air in the immediate vicinity of local sources. Important indoor sources include candles and biomass burning whereas traffic and occasionally forest fires are the major outdoor sources of black carbon exposure. Concentrations of black carbon decrease sharply with increasing distance from (traffic) sources, which makes it an atypical component of particulate matter. High peak concentrations are encountered during car driving.

The public health benefits of reduction in the amount of soot and other particulate matter has been recognised for years. By reducing black carbon, a primary component of fine particulate matter, the health risks from air pollution will decline.

Another form of particulate matter is dust. Road dust consists of deposition of vehicle exhausts and industrial exhausts, tyre and brake wear, dust from unpaved roads or potholes, and dust from construction sites. Road dust is a significant source contributing to the generation and release of particulate matter into the atmosphere. Airborne dust can arise from a wide variety of anthropogenic sources, including the following (Ministry for the Environment, NZ, 2001): wind-blown dust from exposed surfaces, such as bare land and construction sites, wind-blown dust from stockpiles of dusty materials such as sawdust, coal, fertiliser, sand and other minerals, dust caused by vehicle movements on sealed or unsealed roads, agriculture and forestry activities, mines and quarries, road works and road construction, housing developments, municipal landfills and other waste handling facilities, dry abrasive blasting, numerous industrial operations, including grain drying and storage, timber mills, stonemasons, mineral processing, cement handling and batching, and fertiliser storage and processing. Large quantities of dust can also be generated from natural sources, such as dry river beds, pollen from plants and volcanic eruptions.

The potential health effects of dust are closely related to particle size. Particle sizes are normally measured in microns, and the size range of airborne particles is typically from less than 0.1 microns up to about 500 microns, or half a millimetre. Human health effects of airborne dust are mainly associated with particles less than about 10 microns in size (PM_{10}), which are small enough to be inhaled (Ministry for the Environment, NZ, 2001). Nuisance effects can be caused by particles of any size, but are most commonly associated with those larger than 20 microns. PM_{10} dust is associated with a range of effects on health, including effects on the respiratory (asthma) and cardiovascular systems.

Another impact from particulate matter in high concentrations is reduced visibility, resulting in traffic accidents.

5.1.1.5 Sulpher dioxide (SO_x)

Sulphur oxides are formed from the oxidation of sulphur contained in the fuel during combustion (Lane & Vanderschuren, 2010). Sulphur dioxide emissions mostly originate from diesel motors, as the emission of SO_2 depends on the sulphur content of the fuel (Central European University, 2002). It can cause respiratory disease, damage the fabric of buildings and contribute to acid rain (Lane & Vanderschuren, 2010).

5.1.1.6 Toxic heavy metals (TM)

Lead (Pb) has traditionally been used as an additive for vehicles' fuel, in the form of Tetra-ethyl lead. Due to the toxic impact on human health and incompatibility with emission control systems (such as the catalytic converter and introduction of lead free petrol), its presence in developed countries has nearly been eliminated. Some developing countries, however, still allow its use (Dalkmann, Sakamoto, & al., 2011). Lead is a neurotoxin, which has negative impacts on neurological development of children, and also causes cardiovascular problems for adults (Central European University, 2002).

5.1.1.7 Volatile organic compounds (VOC)

Volatile organic compounds arise from the evaporation of fuel and are also an ingredient in ozone production (Gilbert & Perl, 2008). Many of these compounds are also greenhouse gases, like methane (CH4). VOC' biggest impact on health comes from the risk of cancer related to benzene, toluene and xylene (Dalkmann, Sakamoto, & al., 2011).

5.1.2 Factors influencing the extent of air pollution

A range of factors influence emission of pollutants from mobile sources, including (Haq, et al., 2011): vehicle or fuel characteristics such as engine type and technology, fuel injection, type of transmission system and other engine features such as the exhaust, crankcase, catalytic converters, exhaust gas recirculation, age, mileage, engine mechanical condition and adequacy of maintenance and the fuel properties and quality. Fleet characteristics that can influence air pollution are the vehicle mix (number and type of vehicles in use), vehicle utilisation (kilometres per vehicle per year) by vehicle type, age profile of the vehicle fleet, emission standards in effect and incentives or disincentives for the purchase of cleaner vehicles, adequacy and coverage of fleet maintenance programs and implementation of clean fuels programs. Operating characteristics such as altitude, temperature, humidity (for NO_x), vehicle use patterns (number and length of trips), number of cold starts, speed, loading, aggressiveness of driving behaviour, degree of traffic congestion, capacity and quality of road infrastructure, traffic control systems and transport demand management programs can also contribute to air quality impact levels.

5.1.3 Geographical reach of impacts

Air pollution is rarely localised. The prevailing wind direction (concentration of pollutants is higher downwind of the road), weather conditions (rainfall, humidity, temperature), vegetation (filters pollutants) and topography (as physical barriers to pollutants) are the key factors influencing what the range of impacts can be (Tsunokawa & Hoban, 1997).

Fischer (2006) classified air pollutants into global, regional and local impacts. The air pollutants that were portrayed as being relevant on a global scale in terms of the greenhouse effect include CO_2 (carbon dioxide), CH_4 (methane) and N_2O (nitrous oxide). Those that were said to be effective at the regional scale, leading to photochemical smog and acidification, include SO_2 (sulphur dioxide), NO_x (total oxides of nitrogen), NMVOC (non-methane hydrocarbons) and CO (carbon monoxide). Finally, those that were said to be of local significance include PM (particulate matter), HM (heavy metals), SO_2, NO_x, NMVOC and CO.

5.1.4 Additional notes on air pollution

A lack of emission controls on vehicles, and poor monitoring and enforcement systems, exacerbate pollution problems in Sub-Saharan Africa. As the cities in this region undergo urbanisation, motorisation and economic development, the environmental risks to human health, due to air pollution, generally increases at lower levels of development (Haq, et al., 2011). It needs to be noted that changes in temperature, precipitation and cloud cover also impacts local air quality (Lane & Vanderschuren, 2010).

5.2 Biodiversity impacts

The uptake and fragmentation of land for infrastructure (especially road infrastructure) is deemed a negative environmental impact, as it causes habitat fragmentation and divides the ecosystem into smaller, partially isolated units (OECD, 1997). This can result in the destruction of habitats, injury to, or killing of, animals and threats to the survival of populations of individual species. Furthermore, the diversity of species in ecosystems is a function of the total size of the area of habitat, thus dividing this area with a road can cut diversity in half, rather than reducing it only by the actual area used by the infrastructure (OECD, 1997).

If the construction of road infrastructure is not carefully planned, especially in sensitive areas, it can destroy or seriously damage natural ecosystems, thus causing direct damage through loss of habitats for sensitive plants and animals, which is the main cause of biodiversity loss.

Roads cause fragmentation of habitats, preventing free movement of animals and the exchange of genetic material (Central European University, 2002). Habitat fragmentation damages ecosystems' stability and health and can cause corridor restrictions. Corridors are routes that animals use for satisfying their everyday or seasonal needs for food, breeding, and shelter. By cutting through the corridors, the transport infrastructure causes negative pressures on animal populations affecting their feeding or breading, because they are either reluctant to cross the roads or get killed while crossing it. It is also the case that some animals are attracted to roads for various reasons - more food, shelter from predators, or easier movement - which often leads to increased mortality due to accidental deaths.

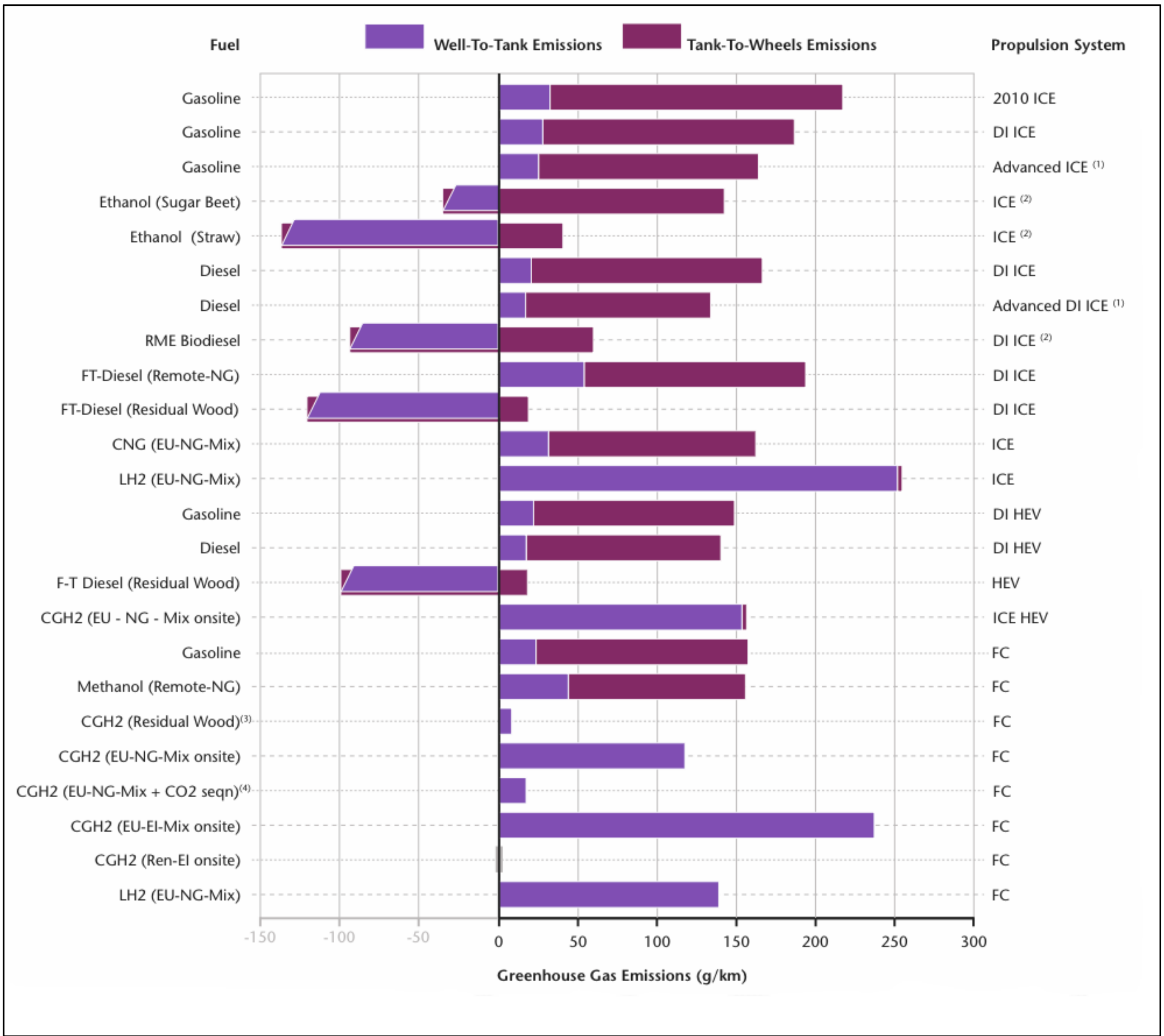
Road construction also opens the ways for intruding species, disrupting in this way the ecological balance of the ecosystems (Central European University, 2002).

5.3 Greenhouse effect

The two main greenhouse gases produced by fossil fuel combustion are carbon dioxide (CO_2) and methane (CH_4). Carbon dioxide emissions are directly dependent on the quantity of the fuel burned, because there is no available technology for its subsequent removal. The only way to presently lower CO_2 emissions is to use fuels with lower carbon contents or to lower fuel use by improving energy efficiency (Central European University, 2002).

Not all greenhouse gases contribute equally to global warming. For example: the emissions from 1kg of CH_4 are equal to the emissions of 21kg of CO_2 (Zhou, Jiang, & Qin, 2007).

Figure 5.1Figure 5.1 illustrates the differences in well-to-wheels emissions of various fuel and propulsion system combinations.



(Dalkmann, Sakamoto, & al., 2011)

Figure 5.1 Well-to-wheel GHG emissions for different fuel and propulsion systems (1) Estimated by VKA (2) Estimated by BP, from GM data (3) Net output from energy use in conversion process (4) Based on Hydro Figures

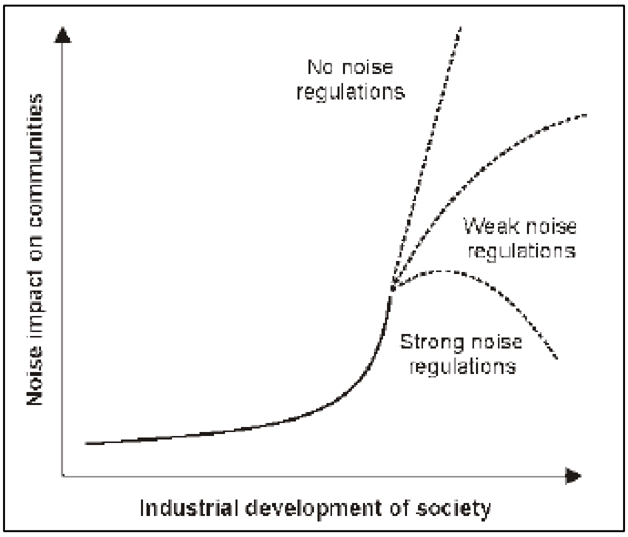
Aviation contributes to levels of GHGs more radically than other modes of transport. It affects the regional and global climate by increasing CO_2, water vapour (H_2O), and tropospheric ozone (O_3), and by reducing methane (CH_4) and stratospheric ozone (Williams, et al., 2007). At cruise altitudes (in the upper troposphere) emissions of NO_2 increases levels of O_3, contributing to global warming. In the global annual mean this is offset by cooling, due to a reduction in CH_4 due to the emission of NO_2, but the spatial and temporal patterns mean the climate impacts are very different. Warming due to ozone is concentrated at northern hemisphere mid-latitudes, whilst cooling due to reduced methane is a global effect (Williams, et al., 2007). Carbon dioxide is a long-lived gas, uniformly mixed in the atmosphere. The location or altitude of emission will have no impact on its contribution to climate change. In contrast, the climate impact of nitrogen oxides is heavily dependent on altitude, latitude, season and on background levels of atmospheric species. Emissions on or near the surface will have very different impacts than those at cruise altitudes (Williams, et al., 2007).

Emissions of water vapour in the stratosphere (by long haul flights at high altitudes) are long lived and can have a significant warming effect. Exhaust gases mixing with surrounding air can condense (onto exhaust particulates or background aerosol) due to the cold temperatures. This rapidly freezes to form contrails. In certain conditions, contrails can last for hours and spread to form extensive cirrus clouds, which are believed to have a further warming impact. During daytime the warming effect of contrails is offset by a cooling (albedo) effect, as the contrail reflects solar radiation (increasing the albedo of the atmosphere). At night the only impact is to trap heat radiated from the surface so the impact changes to warming. Contrail impacts depend on time and location of formation, the microphysics of the contrail, its lifetime, the rate at which it expands and dissipates and the drift of contrails with wind circulation. There is also seasonal variability: contrails form at lower altitudes in winter than in summer and have a greater radiative impact, with winter flights contributing a fifth of traffic, but half the annual radiative forcing (Williams, et al., 2007). Cirrus cloud enhancement could add almost twice the CO_2 effect of the regular CO_2 emissions of a flight (Gilbert & Perl, 2008). The mixture of exhaust species discharged from an aircraft perturbs radiative forcing, which are two to three times more than if the exhaust were CO_2 alone. Also, the impact of burning fossil fuels at altitude is approximately double that of burning the same fuels at ground level (Lee, Lukachko, & Waitz, 2004).

5.4 Noise pollution

5.4.1 Noise pollution defined

The World Health Organisation (2000) defines environmental noise as noise emitted from all sources, except noise at the industrial workplace. Many developed countries have regulations on environmental noise from road, rail and air traffic. In contrast, few developing countries, particularly in Sub-Saharan Africa, have regulations on environmental noise (Haq, et al., 2011). There is a direct relationship between the degree of noise exposure of the public and the level of development in a country. As a society develops, it increases its level of urbanisation and industrialisation, and the extent of its transportation system (Figure 5.2). Each of these developments brings an increase in noise load.



(Hede, 1998)

Figure 5.2 Relationship between noise impact and development

5.4.2 The effects of noise pollution

If the dBA scale is applied to everyday activities, then 0 dBA identifies the threshold of human hearing. A quiet bedroom would generally have a noise level of a little under 40 dBA and a busy office 60 dBA. At around 65 dBA, verbal communication starts to become difficult. A daily L_{eq} of greater than 65 dBA is normally taken as an absolute upper acceptable limit and is used in regulations concerning sound insulation (Haq, et al., 2011). A heavy truck travelling along a road close to where the noise is being measured may produce 90 dBA, a level of noise that may cause hearing impairment if people are continuously exposed to it. Older style or large jet aircraft may produce more than 100 dBA. A noise level of 120 dBA represents the threshold of pain (Haq, et al., 2011).

Adverse health effects of noise include (Haq, et al., 2011): noise-induced hearing impairment, cardiovascular effects, cognitive effects, disturbance of rest and sleep, psychophysiological, mental-health and performance effects, effects on behaviour and annoyance, as well as interference with intended activities.

Hearing impairment is typically defined as an increase in the threshold of hearing. Hearing deficits may be accompanied by tinnitus (ringing in the ears). The main social consequence of hearing impairment is the inability to understand speech in daily living conditions, and this is considered to be a severe social disability.

Sufficient evidence exists for the association between aircraft noise and high blood pressure and the use of cardiovascular medication. Road traffic noise exceeding 60 to 65 dBA during day-time and 50 to 55 dBA during night-time suggests an increase of cardiovascular risk (Babisch & van Kamp, 2009). The most common cardiovascular problems caused by being exposed to road noises are hypertension, arteriosclerosis, Ischaemic and heart disease (IHD) (Dalkmann, Sakamoto, & al., 2011).

Cognitive performance is adversely affected by noise through speech interference. Speech interference is basically a masking process, in which simultaneous interfering noise renders speech incapable of being understood (Haq, et al., 2011). Environmental noise may also mask other acoustical signals that are important for daily life, such as door bells, telephone signals, alarm clocks, fire alarms and other warning signals, and music. The inability to understand speech results in a large number of personal disadvantages and changes in behaviour. Particularly vulnerable are those with impaired hearing, the elderly and children in the process of language and reading acquisition, and individuals who are not familiar with the spoken language.

Sleep disturbance is a major effect of environmental noise. It may cause primary effects during sleep, and secondary effects that can be assessed the day after night-time noise exposure. The secondary, or after-effects, the following morning or day(s) include reduced perceived sleep quality, increased fatigue, depressed mood or well-being and decreased performance (Haq, et al., 2011).

Noise can produce a number of social and behavioural effects, as well as annoyance. These effects are often complex, subtle and indirect and many effects are assumed to result from the interaction of a number of non-auditory variables. The effect of community noise on annoyance can be evaluated by questionnaires or by assessing the disturbance of specific activities. However, it should be recognised that equal levels of different traffic and industrial noises cause different magnitudes of annoyance. This is because annoyance in populations varies not only with the characteristics of the noise, including the noise source, but also depends, to a large degree, on many non-acoustical factors of a social, psychological, or economic nature (Haq, et al., 2011). The correlation between noise exposure and general annoyance is much higher at group level than at individual level. Noise above 80 dBA may also reduce helping behaviour and increase aggressive behaviour. There is particular concern that high-level continuous noise exposures may increase the susceptibility of school children to feelings of helplessness.

Stronger reactions have been observed when noise is accompanied by vibrations and contains low-frequency components, or when the noise contains impulses, such as with shooting noise. Temporary, stronger reactions occur when the noise exposure increases over time, compared to a constant noise exposure. In most cases, $L_{Aeq,\,24h}$ and L_{dn} are acceptable approximations of noise exposure related to annoyance. There is no consensus on a model for total annoyance due to a combination of environmental noise sources. (Haq, et al., 2011).

Figure 5.3 summarises the effects of noise pollution.

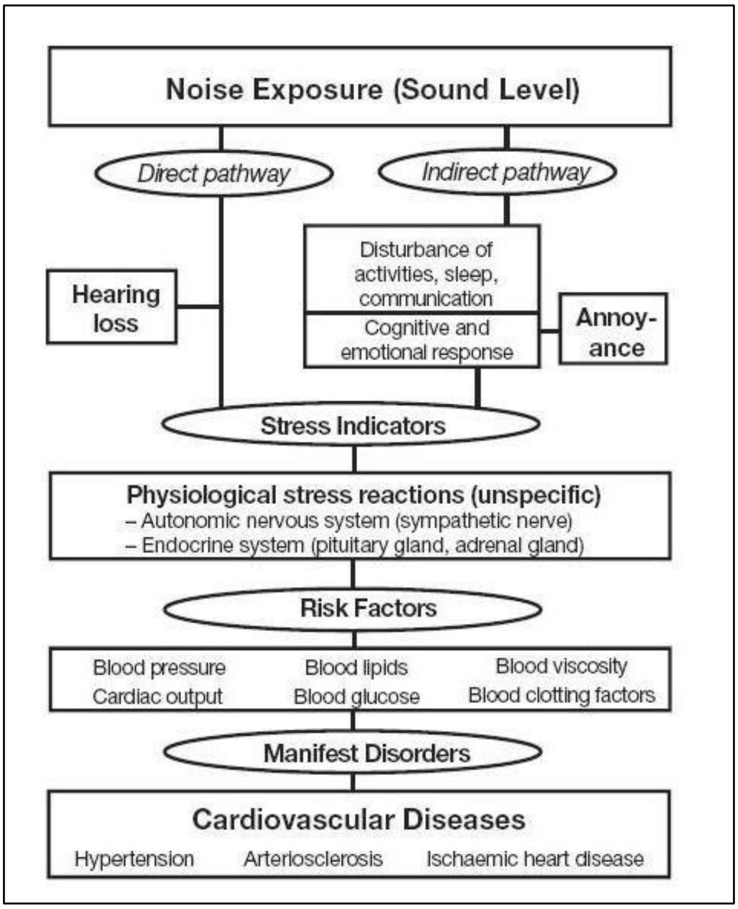
5.4.3 The key causes of noise pollution

Major sources of environmental noise include road, rail, air and sea traffic (Burgemeister & Johnson, 2012). In general, larger and heavier vehicles emit more noise than smaller and lighter vehicles (exceptions: helicopters and two- and three- wheeled motorised road vehicles). Road vehicle noise is mainly generated from the engine and from frictional contact between the vehicle tyres and the ground and air (Haq, et al., 2011). In general, road contact noise exceeds engine noise at speeds higher than 60 km/h.

Railway noise depends primarily on the speed of the train, but also on the type of engine, wagons, and rails and their foundations as well as the roughness of wheels and rails (Haq, et al., 2011). Small radius curves in the track can lead to wheel squeal. Noise can be generated in stations because of running engines, whistles and loudspeakers and in marshalling yards because of shunting operations. High-speed trains create sudden, rises in noise. At speeds above 250 km/h, the proportion of high frequency sound energy increases. Additional noise can arise in areas close to tunnels, in valleys or in areas where the ground conditions help generate vibrations.

Aircraft operation generates substantial noise in the vicinity of airports (Haq, et al., 2011). Aircraft take-offs are known to produce intense noise, including vibration and rattle. At landings intense noise is produced by the landing gear, automatic power regulation, and application of reverse thrust. In general, larger and heavier aircraft produce more noise than lighter aircraft. The sound pressure level from aircraft typically depends upon the number of aircraft, the types of airplanes, their flight paths, the proportions of take-offs and landings, and the atmospheric conditions.

Sources of sea traffic noise include ships, ferryboats, jet skis, and sea motors which all emit high noise levels (Haq, et al., 2011).



(Dalkmann, Sakamoto, & al., 2011)

Figure 5.3 Schematic representation of noise effects

5.5 Resource consumption

5.5.1 Non-renewable fossil fuels

Gilbert and Perl (2008) relate the notion of sustainability to the prevalent use of non-renewable fossil fuels (such as coal, natural gas and oil) in transportation systems globally. The argument is that the excessive use of these primal energy sources may deplete them, and deprive future generations' use of it as a source of energy.

Consumption of, and dependence on, non-renewable natural resources is considered a major negative impact of transport on the earth (Lane & Vanderschuren, 2010). Fossil fuels are the primary energy source for transport.

5.5.2 Other resources

To be constructed, transport infrastructure requires a substantial amount of concrete and steel. In order to produce vehicles, metals and plastic are required. The extraction and production of all these materials cause damage to the environment (Central European University, 2002).

5.6 Soil impacts

5.6.1 Soil contamination

Pollution of soils in close vicinity of roads by chromium, lead, and zinc, may be a result of very busy traffic. These metals tend to remain in the soil for several hundred years and cause damage to the soil micro-organisms and vegetation. These effects are localised on the narrow area on both sides of the road (Central European University, 2002). Soil pollution can also be caused by leaks from underground fuel storage facilities (Gilbert & Perl, 2008).

5.6.2 Erosion

Transport infrastructure construction often requires at least a partial clearance of vegetation. This often leads to erosion as an indirect effect of construction (Central European University, 2002; Lane & Vanderschuren, 2010). In some cases, erosion may occur far from the transport infrastructure that actually causes it, as a result of cumulative impacts.

5.6.3 Other soil related impacts

Unfortunately, the soil best for building transport infrastructure is also typically best for agriculture, because it is stable and flat. Therefore, transport infrastructure development inevitably leads to the loss of reproductive soil for agriculture, and thus causes damages to the socioeconomic development of an area (Central European University, 2002). Not only does the soil covered by the transport infrastructure become lost, but also adjacent soil, which is damaged by the construction works as a result of compaction by heavy machinery.

5.7 Water impacts

Water pollution is the contamination of water bodies (e.g. lakes, rivers, oceans, aquifers and groundwater). Water pollution occurs when pollutants are directly or indirectly discharged into water bodies without adequate treatment to remove harmful compounds. The main causes of water pollution are: storm water run-off (contaminating the water with petroleum hydrocarbons, including fuels (gasoline, diesel fuel, jet fuels, and fuel oil) and lubricants (motor oil), and fuel combustion by-products such as heavy metals), improper storage of fuels (contaminating water sources with volatile organic compounds such as industrial solvents, industrial discharges (especially sulphur dioxide from power plants) causing acidity, acid mine drainage, run-off from construction sites, logging, slash and burn practices or land clearing sites. Airports cause land and water pollution when chemicals used for de-icing seep into the ground (Lane & Vanderschuren, 2010). Hydrologic impacts refers to changes in surface (streams and rivers) and groundwater flows.

5.7.1 Storm water

Storm water is water that originates during precipitation events. Storm water that does not soak into the ground becomes surface runoff, which either flows directly into surface waterways or is channelled into storm sewers, which eventually discharge to surface waters. Storm water is of concern for two main issues: one related to the volume and timing of runoff water (flooding) and the other related to potential contaminants that the water is carrying, i.e. water pollution. Storm water is also a resource and ever growing in importance as the world's human population demand exceeds the availability of readily available water. Techniques of storm water harvesting with point source water management and purification can potentially make urban environments self-sustaining in terms of water.

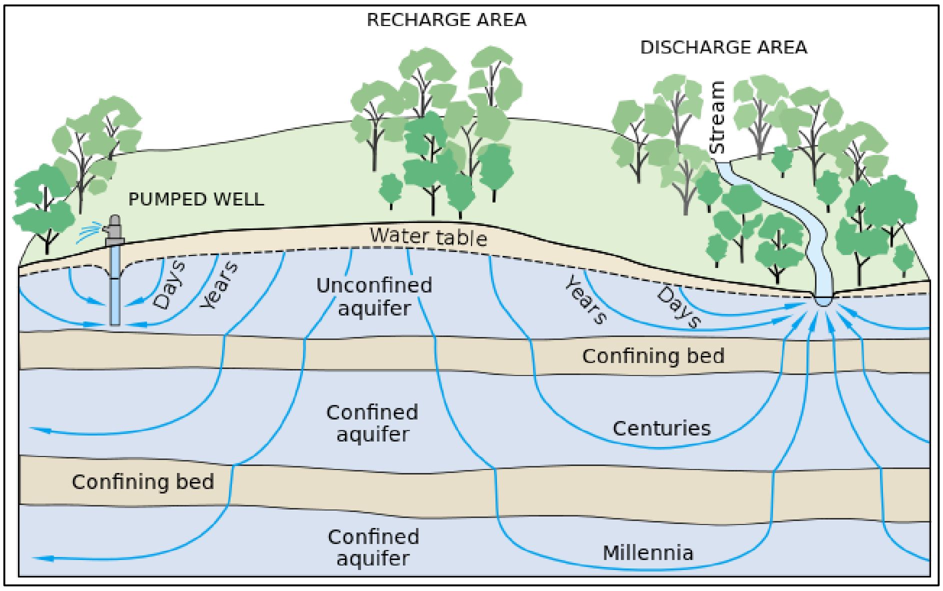
5.7.2 Ground water

Ground water is the water located beneath the earth's surface in soil pore spaces and in the fractures of rock formations (Figure 5.4). A unit of rock or an unconsolidated deposit is called an aquifer when it can yield a usable quantity of water. The depth at which soil pore spaces or fractures and voids in rock become completely saturated with water is called the water table. Groundwater is recharged from, and eventually flows to, the surface naturally; natural discharge often occurs at springs and seeps, and can form oases or wetlands. Groundwater is also often withdrawn for agricultural, municipal, and industrial use by constructing and operating extraction wells.

Groundwater makes up about 20% of the world's fresh water supply, which is about 0.6% of the entire world's water, including oceans and permanent ice. This makes it an important resource that can act as a natural storage that can buffer against shortages of surface water, as in during times of drought.

Groundwater is naturally replenished by surface water from precipitation, streams, and rivers when this recharge reaches the water table. Recent research has demonstrated that evaporation of groundwater can play a significant role in the local water cycle (Figure 5.5), especially in arid regions.

Water pollution of groundwater, from pollutants released to the ground that can work their way down into groundwater, can create a contaminant plume within an aquifer. Movement of water and dispersion within the aquifer spreads the pollutant over a wider area, its advancing boundary, often called a plume edge, which can then intersect with groundwater wells or daylight into surface water such as seeps and springs, making the water supplies unsafe for humans and wildlife. Water table conditions are of great importance for drinking water supplies, agricultural irrigation, waste disposal (including nuclear waste), wildlife habitat, and other ecological issues.

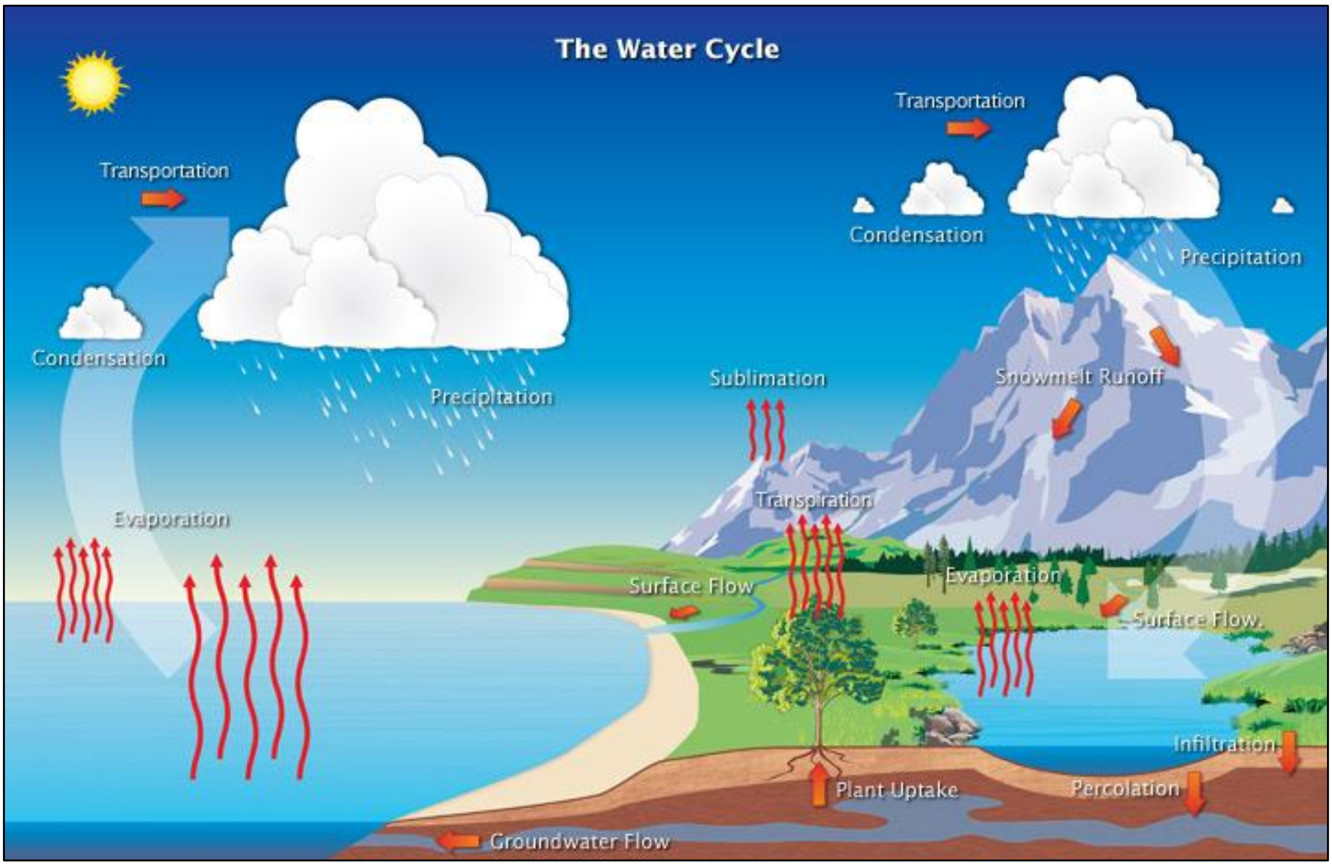


(http://pubs.usgs.gov/circ/circ1139/)

Figure 5.4 The ground water system

5.7.3 Surface water

Surface water is water on the surface of the planet such as in a stream, river, lake, wetland, or ocean. Non-saline surface water is replenished by precipitation and by recruitment from ground water. It is lost through evaporation, seepage into the ground (where it becomes ground water), used by plants for transpiration, abstracted by mankind for agriculture, living and industry or discharged to the sea, where it becomes saline (Figure 5.5).



(www..education.noaa.gov)

Figure 5.5 The water cycle

5.7.4 Relationship between impervious surfaces and surface runoff

Physical infrastructure is the main cause of negative impacts on water from road transport. The roads themselves, parking lots, compacted soil, driveways and other paved surfaces lead to an increase in impermeable surfaces, particularly in urban areas. Impermeable surfaces interrupt the filtration of rainfall into the ground water, which aggravates flood risk and leads to more pollutant run-off into surface waters in heavy rains (OECD, 1997). This run-off may contain build-up from fuel and lubricant losses, spillages due to accidents and material wear, dust and wind deposits (Gilbert & Perl, 2008). Roads and parking lots are major sources of polycyclic aromatic hydrocarbons (PAHs), which are created as combustion by-products of gasoline and other fossil fuels, as well as of the heavy metals nickel, copper, zinc, cadmium, and lead. Table 5.1 contains a summary of the sources of heavy metals from the transportation system (where Cd = cadmium, Co = cobalt, Cr = chromium, Cu = copper, Fe = iron, Mn = manganese, Ni = nickel, Pb = lead and Zn = zinc). Some heavy metals bio-accumulate in the food chain and can become toxic to humans over the long run (Nixon & Saphores, 2007).

Because impervious surfaces do not allow rain to infiltrate into the ground, more run-off is generated than in the undeveloped condition. This additional run-off can erode watercourses (streams and rivers), as well as cause flooding after the storm water collection system is overwhelmed by the additional flow. Because the water is flushed out of the watershed during the storm event, little infiltrates the soil, replenishes groundwater, or supplies stream base flow in dry weather – this can ultimately lead to water shortages. Changes in water tables negatively affect vegetation, increase risk of erosion, and often cause loss of water for drinking and agriculture.

Table 5.1 Transportation sources of heavy metals

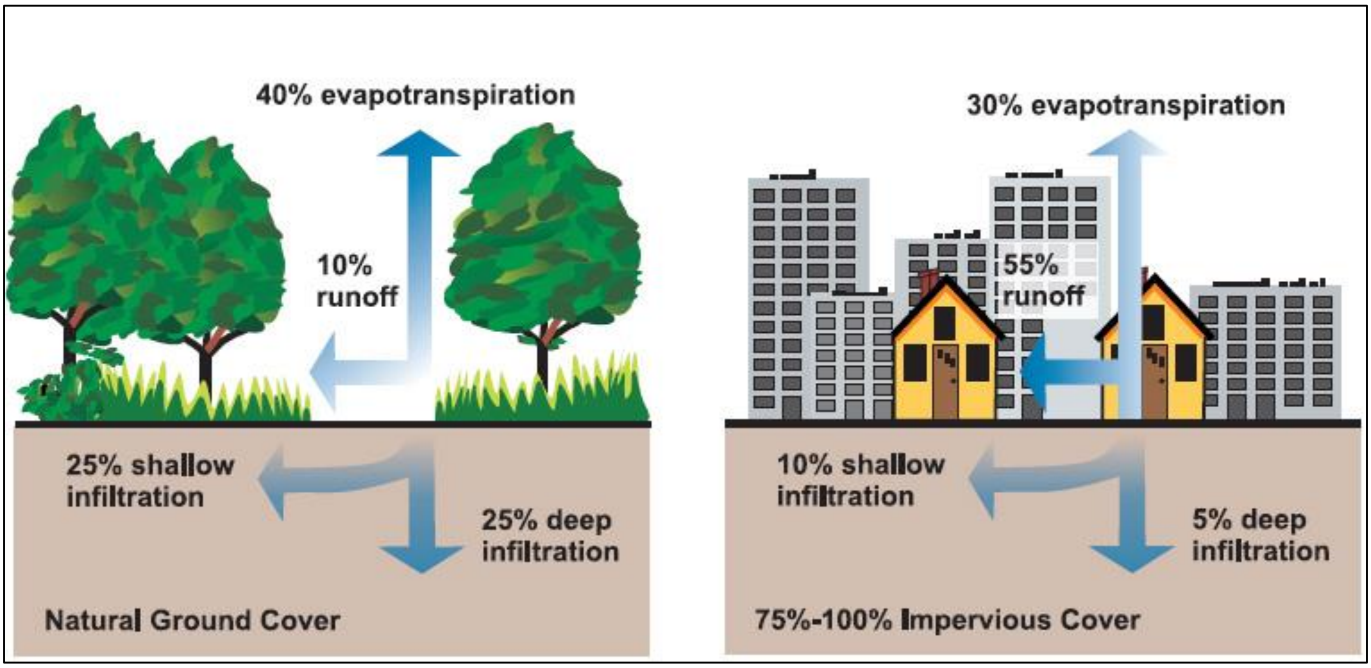
Source	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Gasoline	•			•				•	•
Exhaust							•	•	
Motor oil and grease		•			•		•	•	•
Antifreeze	•		•	•	•			•	•
Undercoating								•	•
Brake linings				•	•		•	•	•
Rubber	•			•				•	•
Asphalt				•			•		•
Concrete				•			•		•
Diesel oil	•								
Engine wear					•	•	•	•	•

(Nixon & Saphores, 2007)

A “first flush” is the initial runoff of a rainstorm. During this phase, polluted water entering storm drains in areas with high proportions of impervious surfaces is typically more concentrated compared to the remainder of the storm. Consequently, these high concentrations of urban runoff result in high levels of pollutants discharged from storm sewers to surface waters. Most municipal storm sewer systems discharge storm water untreated to streams, rivers and bays. Pollutants entering surface waters during precipitation events are termed polluted runoff. Daily human activities result in deposition of pollutants on roads, lawns, roofs, farm fields, etc. When it rains or there is irrigation, water runs off and ultimately makes its way to a river, lake, or the ocean. While there is some attenuation of these pollutants before entering the receiving waters, the quantity of human activity results in large enough quantities of pollutants to impair these receiving waters.

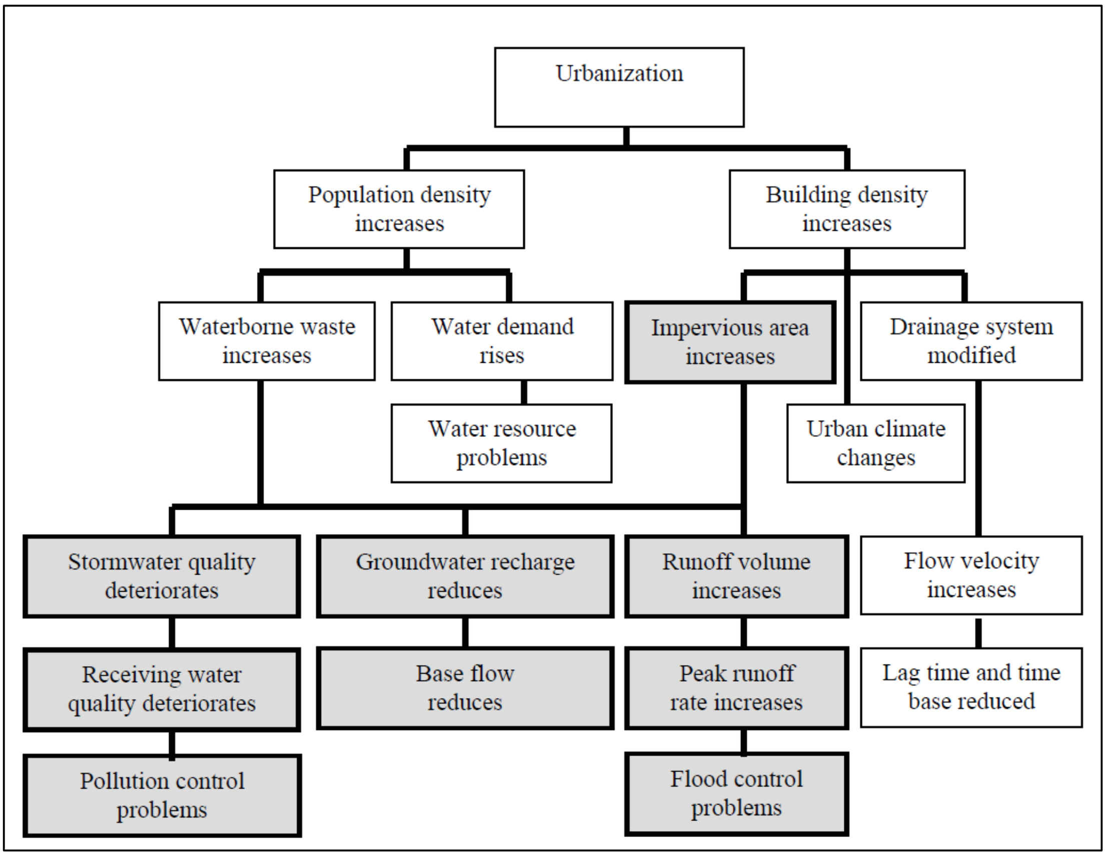
Eroding soils or poorly maintained construction sites can often lead to increased sedimentation in runoff. Sedimentation often settles to the bottom of water bodies and can directly affect water quality. Excessive levels of sediment in water bodies can increase the risk of infection and disease through high levels of nutrients present in the soil. These high levels of nutrients can reduce oxygen and boost algae growth while limiting native vegetation growth. Limited native vegetation and excessive algae has the potential to disrupt the entire aquatic ecosystem due to limited light penetration, lower oxygen levels, and reduced food reserves. Excessive levels of sediment and suspended solids have the potential to damage existing infrastructure as well. Sedimentation can increase runoff by plugging underground injection systems, thereby increasing the amount of runoff on the surface. Increased sedimentation levels can also reduce storage behind reservoirs. This reduction of reservoir capacities can lead to increased expenses for public land agencies while also impacting the quality of water recreational areas. As storm water is channelled into storm drains and surface waters, the natural sediment load discharged to receiving waters decreases, but the water flow and velocity increases. In fact, the impervious cover in a typical city creates five times the runoff of a typical woodland of the same size (Figure 5.6). The run-off also increases temperatures in streams, harming fish and other organisms.

One of the most pronounced effects of urban run-off is on watercourses that historically contained little or no water during dry weather periods (often called ephemeral streams). When an area around such a stream is urbanised, the resultant runoff creates an unnatural year-round stream flow that hurts the vegetation, wildlife and stream bed of the waterway. Containing little or no sediment, relative to the historic ratio of sediment to water, urban run-off rushes down the stream channel, ruining natural features such as meanders and sandbars, and creates severe erosion—increasing sediment loads at the mouth while severely incising the stream bed upstream. Excessive stream bank erosion may cause flooding and property damage.



(EPA, 2003)

Figure 5.6 The impact of impervious surfaces and surface run-off



(Hurd & Civco, 2004)

Figure 5.7 Hydrologic impact of urbanisation

Basically, stream hydrology and function are dependent on five variables: climate, geology, soils, land use, vegetation (Brabec, Schulte, & Richards, 2002). These affect discharge and sediment load, influencing the hydrology and morphology of the stream. Land use and vegetation are the only factors of these over which man has direct control. Although the impervious surface does not directly generate pollution, a clear link has been made between impervious surface and the hydrologic changes that degrade water quality. An impervious surface is a characteristic of urbanisation. The hydrologic impact of increases impervious surfaces (marked in grey) is indicated in Figure 5.7. Several studies have shown that stream quality declines at 10% to 15% imperviousness in an area (Brabec, Schulte, & Richards, 2002).

It should be noted that pervious surfaces can also contribute to water pollution. Table 5.2 shows a comparison of runoff characteristics for a variety of pervious surfaces.

Table 5.2 Comparison of runoff characteristics for a variety of pervious surfaces

Surface	Runoff volume	Nitrate	Soluble phosphorus	Total suspended solids
Gravel driveway	0.51	0.03	0.06	692
Bare soil	0.33	0.32	0.79	1935
Cold-season grass, sodded	0.05	0.31	1.12	29
Warm-season turf	0.03	0.44	0.33	43
Mulched landscape	0	0	0	0
Meadow	0	0	0	0

(Schueler, 1995)

Nitrogen and phosphorus have been identified as the primary nutrients responsible for algal blooms caused by eutrophication which results in fish die-off, endangers human health, and impacts the economic and recreational use of riverine, palustrine, and estuarine waters (Brabec, Schulte, & Richards, 2002).

The key commonalities between first order environmental impacts generated by transport and secondary water quality impacts are: the emissions of nitrates into the air and runoff from impervious land containing nitrates, phosphorus in the sediment and causing erosion.

5.8 Energy supply impacts

5.8.1 Electricity supply

5.8.1.1 Air pollution and greenhouse gas emissions

Electricity generation is a key contributor to global emissions of greenhouse gases (GHG), NO_x and SO_2 and their related environmental impacts. Life cycle emission factors for electricity generation from selected technologies are presented in Table 5.3. Factors at the top of the table refer to electricity output [kg/MWh_{out}], while values at the bottom of the table refer to fuel input [kg/GJ_{in}].

Other types of air emissions generated are particulate matter, toxic metals (such as mercury) and non-methane volatile organic compounds (NMVOC) that contribute directly to smog formation (Gagnon, Bélanger, & Uchiyama, 2002). Table 5.4 presents the range of values for these emissions.

It can be shown that renewable electricity has the following environmental benefits when compared to fossil-based electricity: reduced air pollution, lower greenhouse gas emissions, lower impacts on watersheds, reduced transportation of energy resources and maintaining natural resources for the long term (Akella, Saini, & Sharma, 2009). Renewable electricity schemes arranged in the order of lowest to highest CO_2 emissions are: large hydropower, wind, geothermal, small hydropower, biomass, solar thermal electric and solar photovoltaic.

Table 5.3 Life cycle emissions of CO_2, NO_x and SO_2 from electricity generation

Energy source	CO_2-eq	NO_x	SO_2
Electricity output [kg/MWh$_{out}$]			
Hard coal	660–1050	0.3–3.9	0.03–6.7
Lignite	800–1300	0.2–1.7	0.6–7
Natural gas	380–1000	0.2–3.8	0.01–0.32
Oil	530–900	0.5–1.5	0.85–8
Nuclear power	3–35	0.01–0.04	0.003–0.038
Biomass	8.5–130	0.08–1.7	0.03–0.94
Hydropower	2–20	0.004–0.06	0.001–0.03
Solar energy	13–190	0.15–0.40	0.12–0.29
Wind	3–41	0.02–0.11	0.02–0.09
Fuel input [kg/GJ$_{in}$]			
Hard coal	46–125	0.028–0.352	0.003–0.596
Lignite	91–141	0.025–0.161	0.047–0.753
Natural gas	57–85	0.037–0.277	0.0002–0.044
Oil	75–94	0.081–0.298	0.112–0.698
Biomass	0.1–10	0.007–0.128	0.004–0.094

(Turconi, Boldrin, & Astrup, 2013)

5.8.1.2 Forest destruction

Acidification, caused by the SO_2 and NO_x emissions from electricity generation, will tend to remove some essential nutrients from soils (K, Ca, Mg) which is bad for forest health (Gagnon, Bélanger, & Uchiyama, 2002). Acid may also mobilise toxic metals, such as aluminium, which can damage roots. Further to this, adding nitrogen, the main nutrient of plants, may create an imbalance in resources and make trees more vulnerable to diseases and frost. Photochemical smog can damage the leaves of trees and plants (Gagnon, Bélanger, & Uchiyama, 2002).

Table 5.4 Emissions of NMVOC, PM and TM from electricity generation

Generation options (classified by level of service)	NMVOC emissions (t/TWh)	Particulate matter emissions (t/TWh)	Mercury emissions (kg Hg/TWh)
Options capable of meeting base load and peak load			
Hydropower with reservoir		5	
Diesel	1570	122–213	
Base load options with limited flexibility			
Natural gas c.c. turbines	72–164	1–10	0.3–1
Bituminous coal: modern	18–29	30–663	1–360
Lignite: old plant		100–618	2–42
Heavy oil: no scrubbing	22		2–13
Hydropower run-of-river		1–5	
Biomass combustion	89	190–320	0.5–2
Nuclear		2	
Intermittent options that need a backup production			
Wind power		5–35	
Solar photovoltaic	70	12–190	

(Gagnon, Bélanger, & Uchiyama, 2002)

5.8.1.3 Resource consumption

Fossil fuels are currently the primary feedstock in global energy provision. These are finite resources residing on the planet and are continually depleted by energy production activities. It is presently not possible to replenish these resources with alternates.

Land requirements from electricity generation activities will gain importance in the future for many reasons (Gagnon, Bélanger, & Uchiyama, 2002): with population growth, more land is required for farms, cities and industries, and land for other uses is becoming scarce, emerging renewable sources of energy, such as wind or solar power require large land areas and alternative sources of biofuels, such as ethanol from crops, require very large areas of farmland.

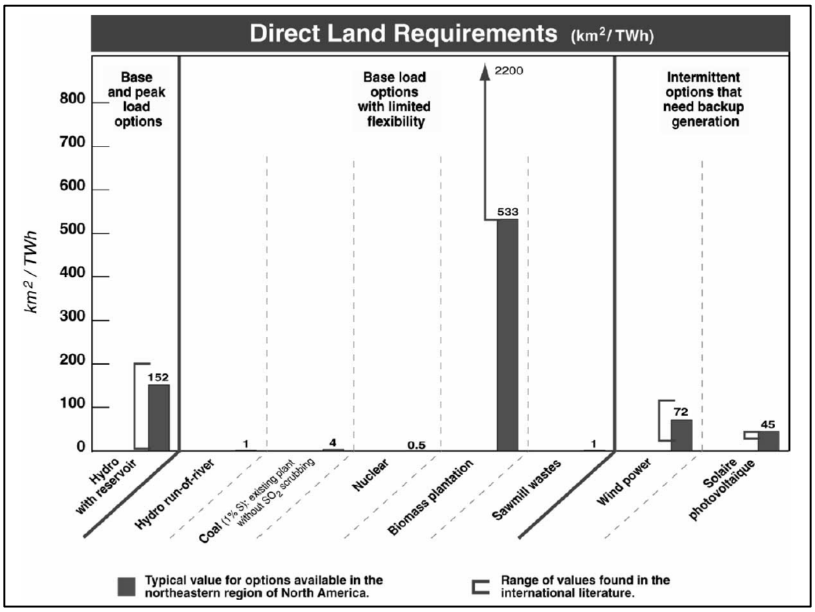
Figure 5.8 compares the land requirements from various electricity generation systems across the globe. All electricity generation systems affect land use, either directly or indirectly. For hydropower, the transformation of forests and land into aquatic ecosystems consumes land. For coal, the large areas affected by mining activities and fallout of acid rain consume land and for biomass, the area of forests that are exploited consume land.

5.8.1.4 Stratospheric ozone depletion

It is well known that the ozone present in the stratosphere, roughly between altitudes of 12 km and 25 km, plays a natural, equilibrium-maintaining role for the earth, through absorption of ultraviolet (UV) radiation and absorption of infrared radiation (Dincer, 1999). A global environmental problem is the distortion and regional depletion of the stratospheric ozone layer, which has been shown to be caused by the emissions of CFCs, halons (chlorinated and brominated organic compounds) and NO_x. Ozone depletion in the stratosphere can lead to increased levels of damaging UV radiation reaching the ground, causing increased rates of skin cancer, eye damage and other harm to many biological species.

5.8.2 Liquid fuels supply

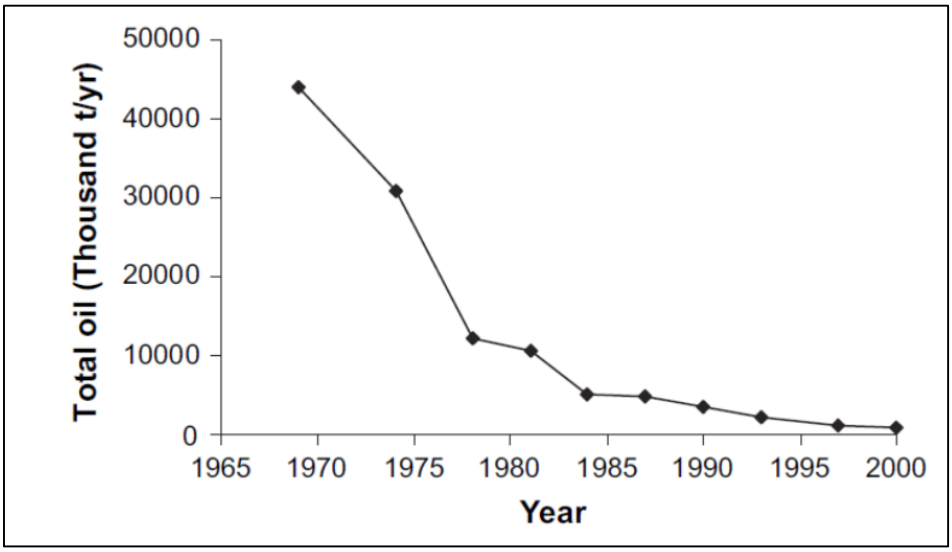
Oil refinery effluents contain many different chemicals at different concentrations including ammonia, sulphides, phenol and hydrocarbons. The exact composition cannot, however, be generalised as it depends on the refinery and which units are in operation at any specific time (Wake, 2005). It is, therefore, difficult to predict what effects the effluent may have on the environment. Toxicity tests have shown that most refinery effluents are toxic, but to varying extents. Some species are more sensitive and the toxicity may vary throughout the life cycle.



(Gagnon, Bélanger, & Uchiyama, 2002)

Figure 5.8 Land use estimates for various electricity generation options

Field studies have shown that oil refinery effluents often have an impact on the fauna, which is usually restricted to the area close to the outfall. The extent of the effect is dependent on the effluent composition, the outfall's position and the state of the recipient environment. It is possible to detect two effects that oil refinery effluent has on the environment (Wake, 2005). Firstly, it has a toxic effect close to the outfall, which is seen by the absence of all or most species. Secondly, there is an enrichment effect which can be distinguished as a peak in the abundance or biomass. These effects are not limited to just oil refinery effluents, which make it difficult to distinguish the effects an oil refinery effluent has from other pollution sources. The discharge from oil refineries has reduced in quantity and toxicity over recent decades, as is evident in Figure 5.9.



(Concawe, 2004)

Figure 5.9 Total oil content in European refinery effluent over time

Gasoline spills from leaking underground fuel storage tanks are a major source of groundwater pollution. Although severe leaks can create fire or explosion hazards, the primary environmental concerns associated with gasoline releases are volatile organic compounds such as dissolved-phase benzene, toluene, ethylbenzene, and xylene (Nixon & Saphores, 2007).

5.9 Infrastructure supply impacts

Land is affected by the transport sector in two ways: directly through building the transport infrastructure, and indirectly by the development induced by the transport sector. One of the most obvious negative effects of the transport infrastructure development on land use is urban sprawl (Central European University, 2002). The growth of urban areas over the surrounding rural land leads to fragmentation of land use control among more localities and segregation of types of land use in different zones. Urban sprawl causes other problems, such as widespread strip commercial development, low-density settlements, and dominance of private motor vehicles in the transportation modes (Central European University, 2002).

Additionally, transportation infrastructure has many other adverse environmental impacts. Abbas (2003) summarised these impacts in Table 5.5.

One of the most noteworthy indirect impacts that infrastructure development and management can have on the environment is the indirect consequences of improvements in fuel consumption. Several studies have shown that well maintained roads (roads in a good condition) substantially improve fuel consumption figures. Bartholomeu and Filho (2009) performed a study in Brazil and found that travel on the best routes resulted in an average 5.1% fuel saving over travel on the worst routes. These degraded roads represent a 58% increase in the consumption of fossil fuels, a 38% increase in vehicle maintenance costs, a 50% increase in the number of accidents and up to a 100% increase in travel time in Brazil (www.cnt.org.br).

Table 5.5 Potential intensity of environmental effects due to road projects

	Environmental effects						
Main phases	**Air pollution**	**Sound pollution**	**Water pollution**	**Solid waste**	**Vibration**	**Visual intrusion**	**Traffic accidents**
Mobilisation	High	High	Low	Low	High	None	Low
Construction	High	Very high	High	High	Very high	None	Low
Operation	Very high	High	High	Very high	High	High	High
Maintenance	High	Very high	High	High	Very high	High	High

(Abbas, 2003)

In South Africa, a large proportion of freight is still transported on the secondary road network, especially in the agriculture, mining and forestry sectors. Comparing fuel consumption between actual road conditions and, firstly, a scenario with 10% better road conditions (Table 5.6), secondly, a scenario with 10% worse road conditions (Table 5.7) and, thirdly, a scenario where freight travelled on the provincial roads as opposed to the national (better kept) roads (Table 5.8), it is found that fuel savings can be achieved due to infrastructure improvement.

Table 5.6 South African corridor fuel consumption comparison scenario one

Freight transport total	Actual road conditions on corridors	10% Improvement in road conditions	Difference	% Decrease from actual
Total annual fuel consumption for all corridors	5 669 502 kℓ	5 665 185 kℓ	4 317 kℓ	0.08%
Total annual fuel costs (based on average diesel price for 2011 of R9.2/ℓ[65])	R52.159 billion	R52.119 billion	R40 million	0.08%
Total annual tyre costs for all corridors	R2.629 billion	R2.624 billion	R5 million	0.16%
Total annual repair and maintenance costs for all corridors – damage caused by vibrations only	R1.958 billion	R1.904 billion	R54 million	2.74%

(CSIR Built Environment, 2013)

Table 5.7 South African corridor fuel consumption comparison scenario two

Freight transport total	Actual road conditions on corridors	10% Deterioration in road conditions	Difference	% Increase from actual
Total annual fuel consumption for all corridors	5 669 502 kℓ	5 674 250 kℓ	4 748 kℓ	0.08%
Total annual fuel costs (based on R9.2/ℓ[65])	R52.159 billion	R52.203 billion	R44 million	0.08%
Total annual tyre costs for all corridors	R2.629 billion	R2.633 billion	R4 million	0.18%
Total annual repair and maintenance costs for all corridors – damage caused by vibrations only	R1.958 billion	R2.017 billion	R59 million	3.02%

(CSIR Built Environment, 2013)

Table 5.8 South African corridor fuel consumption comparison scenario three

Freight transport total	Actual national road network	Actual provincial road network	Difference	% Increase between actual and provincial costs
Total annual fuel consumption for all corridors	5 669 502 kℓ	5 698 366 kℓ	28 864 kℓ	0.51%
Total annual fuel costs (based on R9.2/ℓ)	R52.159 billion	R52.425 billion	R266 million	0.51%
Total annual tyre costs for all corridors	R2.629 billion	R2.657 billion	R28 million	1.08%
Total annual repair and maintenance costs for all corridors – damage caused by vibrations only	R1.958 billion	R2.316 billion	R358 million	18.34%

(CSIR Built Environment, 2013)

The high costs of materials, equipment, inadequate maintenance policies and low institutional capacities have resulted in inadequate levels of maintenance of highways and rural roads in many African countries (Haq, et al., 2011).

5.9.1 Intermodal transportation impacts

Inter-modality is a process of transporting freight 'by means of a system of interconnected networks, involving various combinations of modes of transportation, in which all the component parts are seamlessly linked and efficiently coordinated' (Rondinelli & Berry, 2000). It offers manufacturers a full range of transportation modes and routing options, allowing them to coordinate supply, production, storage, finance and distribution functions to achieve efficient relationships.

As new multimodal transportation hubs are constructed and as existing ports, airports, rail terminals, and trucking and distribution complexes expand to provide intermodal transportation services, the potential environmental impacts associated with each type of transportation can be multiplied and compounded. Development in and around these transportation hubs changes land uses, increases density, and generates more intensive local and cross-town traffic, all of which can create new environmental problems (Rondinelli & Berry, 2000). Figure 5.10 summarises the environmental impacts potentially attributable to multimodal infrastructure hubs.

5.10 Vehicle supply impacts

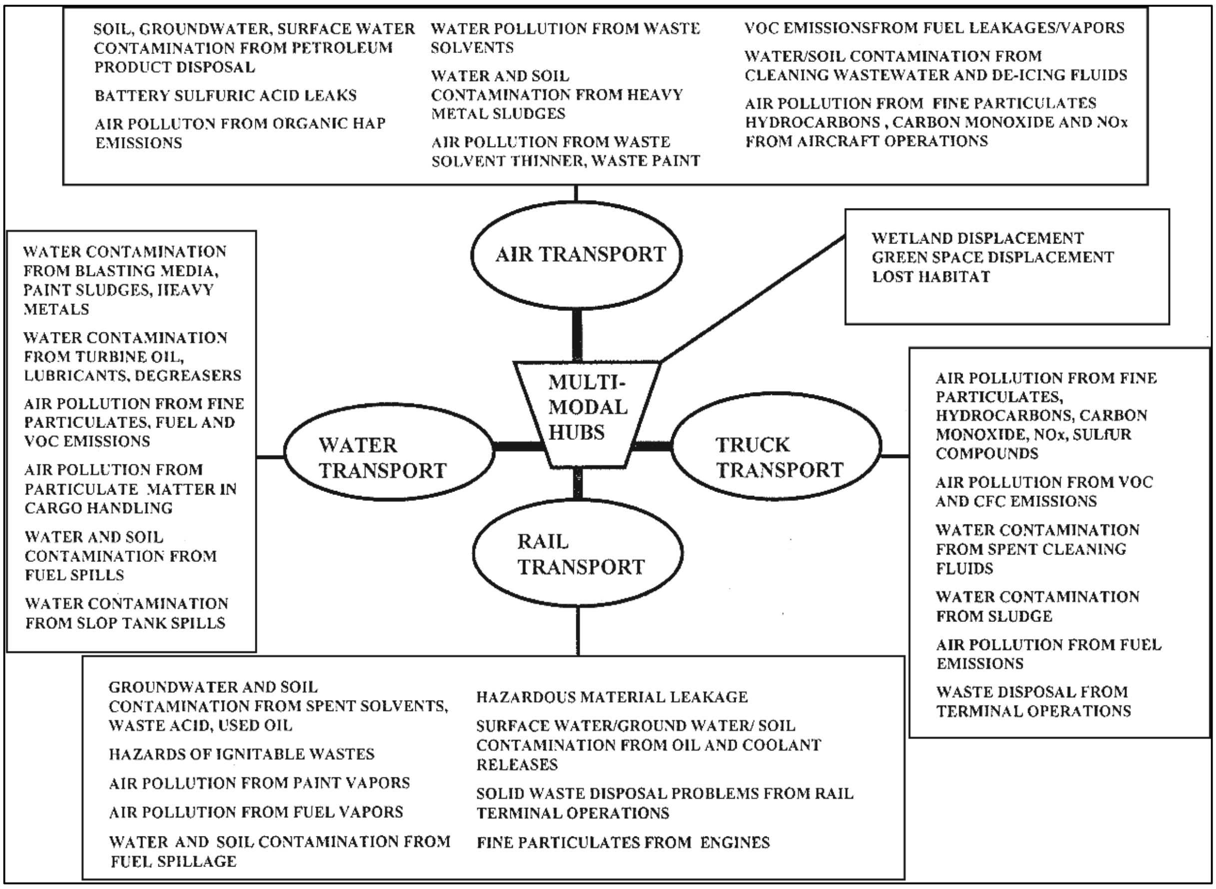
5.10.1 Aircraft maintenance and refurbishment

Maintenance and refurbishing of aircraft and other equipment can have serious environmental impacts, primarily organic HAP emissions from chemical milling maskant application, parts cleaning, and metal finishing using chemical solutions, cyanide, and heavy metal baths. The application of coatings generate organic HAP emissions, and painting emits VOCs (Rondinelli & Berry, 2000). Glycol-based materials used in aircraft de-icing (seen as an airport impact) can run off into surface waters or infiltrate groundwater, depleting oxygen and introducing toxins that adversely affect life forms in water (Rondinelli & Berry, 2000).

5.10.2 Railway maintenance and refurbishment

Wastes from railcar refurbishing and maintenance operations using degreasers, solvents, acids, paint thinners, paints, and epoxies can pollute water and soils and emit VOCs. Locomotive maintenance produces sludge, waste solvents, and cleaners that can cause air pollution and, if ignited, serious threats to human health. Ineffective disposal of all of these materials can cause groundwater and soil contamination (Rondinelli & Berry, 2000).

In terms of railroad operations, the main environmental culprits are: fuelling operations (air pollution from vapours and water and soil contamination from spillage), hazardous material transport (leakage or spillage) and oil and coolant releases (surface and ground water and soil contamination) (Rondinelli & Berry, 2000).



(Rondinelli & Berry, 2000)

Figure 5.10 Multimodal hubs as conduit for transport related environmental impacts

5.10.3 Road vehicle maintenance and refurbishment

Motor oil, brake and transmission fluids, coolants, solvents, and lubricants emit CFCs and VOCs at truck terminals and maintenance facilities, and their improper disposal contaminates soil and water (Rondinelli & Berry, 2000). VOC emissions also come from the detergents, caustic solutions, and solvents used in washing vehicles, and from residuals from shipments and tank cleaning. The same applies for public transport vehicle depots.

5.11 Transport activity impacts

The combustion of fossil fuels during all transport activities is the main source of environmental impacts from the sector. This generates virtually all first order impacts and, as a result, all second and third order impacts associated with said first order impacts.

The transportation of dangerous goods (such as hazardous wastes, oil and chemicals) poses a risk of contamination of soil, waters, and wetlands.

5.12 Second order environmental impacts

5.12.1 Acidification

The problem of acidification is caused by acid depositions which originate from anthropogenic emissions of the three main pollutants: sulphur dioxide (SO_2), nitrogen oxides (NO_x) and ammonia (NH_3) (Central European University, 2002). Acid depositions have a negative impact on water, forests, and soil. They cause defoliation and weakening of trees. Changes in soil and water pH have a harmful effect on soil and aquatic organisms. Damage is also visible on man-made structures, such as limestone and marble buildings and monuments.

5.12.2 Secondary air pollution

Secondary air pollutants are substances created in chemical reactions among primary pollutants. For example, NO_x and HC create ozone (O_3) in the presence of sunlight (Central European University, 2002). Ozone is the principal ingredient in photochemical smog, which is a highly reactive form of oxygen that damages living matter and is implicated in crop damage and respiratory illness in humans (Gilbert & Perl, 2008). Ozone irritates the eyes, damages the lungs, and aggravates respiratory problems. It is our most widespread and intractable urban air pollution problem. Despite all the improvements in the motor vehicle technology in industrialised countries, smog is still a problem in large cities. In developing countries, the situation is even worse because of old vehicles and poor maintenance (Central European University, 2002).

5.12.3 Secondary impacts on biodiversity

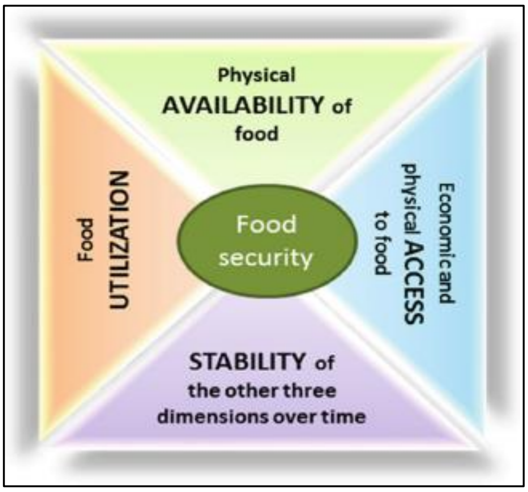
Additional impacts on biodiversity as an indirect consequence of transportation are disturbances to ecosystems, reduced reproductive rates of animals, habitat loss for certain species and upsetting certain food chains in certain ecosystems. Noise, lights, and runoff of hazardous compounds from roads cause disturbance in the ecosystems, and lower the reproduction rates of animals (Central European University, 2002).

Water ecosystems also suffer disruptions caused by the land transport infrastructure. Erosion caused by said infrastructure leads to accumulation of fine earth particles downstream, which affects habitats for fish spawning. Changes in water flow caused by diversions during construction works often have negative effects on plankton, eventually upsetting food chains in the ecosystem (Central European University, 2002).

5.13 The link to food security

The most commonly accepted and used definition for food security, agreed upon at the World Food Summit is: “Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for a healthy and active life” (Sunderland, 2011). It is, thus, not enough to be able to collect or grow food, but the ability to purchase food is also a major factor in ensuring food security, hence the more vulnerable and poorest members of society are particularly at risk from lack of access to food (Sunderland, 2011). In fact, UNEP (2013) distinguishes between four dimensions of food security, shown in Figure 5.11. Sunderland (2011) agrees that access to food must be sustainable in the long term. A household cannot be considered food secure if it has current access to sufficient food to meet immediate nutritional requirements, but this is achieved through depleting the natural capital that would have provided future resources.

The current food security challenge in South Africa consists of two dimensions (South African Government, 2008): the first tries to maintain and increase South Africa's ability to meet its national food requirements, and the second seeks to eliminate inequalities and poverty amongst households that is made apparent by inadequate and unstable food production, lack of purchasing power, poor nutritional status and weak institutional support networks and disaster management systems. Food security is seen as a Constitutional Right in South Africa and the country guarantees its citizens the right to have access to sufficient food and water. Despite national food security (on average), many South African households experience continued food insecurity, malnutrition and unemployment. According to data from Statistics South Africa (StatsSA) (for 2004), approximately 14.3 million South Africans are vulnerable to food insecurity (South African Government, 2008).



(UNEP, 2013)

Figure 5.11 The four dimensions of food security

5.13.1 Biodiversity impacts on agricultural productivity

Biodiversity is key to sustainable, efficient, resilient and nutritious food production (UNEP, 2013). About 7,000 species of plants have been cultivated or collected for consumption in human history. Presently, only about 30 different crops provide 95% of human food energy needs, with five cereal crops (rice, wheat, maize, millet and sorghum) expected to be providing 60% of the energy intake of the world's population by 2050 (UNEP, 2013). In terms of food availability, global food production will need to rise by about 60%.

Although long considered mutually exclusive, biodiversity conservation and food security are two sides of the same coin (Sunderland, 2011). The conventional model to achieve food security has been to convert wild lands to intensive commercial agricultural use, leading to the increased homogenisation of natural landscapes. An immediate result of this model of land use has been a drastic loss of wild lands, the biodiversity they contain and the ecosystem services they provide (Sunderland, 2011). Perrings et al. (2010) suggest that society has "traded off" biodiversity to achieve food security. Approximately 30% to 40% of the earth's surface is now under some sort of agricultural system (Sunderland, 2011).

It is expected that any marked increase in production will undoubtedly be at the expense of currently unproductive lands and that further expansion of industrial agriculture through land conversion could have a continuing devastating effect of the world's remaining biodiversity (Sunderland, 2011).

Biodiversity provides an important safety-net during times of food insecurity, particularly during times of low agricultural production, during other seasonal or cyclical food gaps or during periods of climate induced vulnerability (Sunderland, 2011). The World Health Organisation estimates that in many developing countries up to 80% of the population relies on biodiversity for primary health care (Herndon & Butler, 2010) and the loss of biodiversity has been linked to the increased emergence and transmission of infectious diseases with deleterious impacts on human health (Keesing, et al., 2010).

Moreover, ecological processes such as the maintenance of watershed services, soil fertility, pollination, seed dispersal, nutrient cycling and natural pest and disease control all rely to a greater or lesser extent on biodiversity, or components of it; these are processes that are critical to the maintenance of agricultural systems (Benton, 2007). Bio diverse multi-functional landscapes are more resilient to extreme weather effects and can provide a natural "insurance policy" against climate change (Cotter & Tirado, 2008).

5.13.2 Climate change impacts on agricultural productivity

Recent yield progress due to advances in agriculture is promising in terms of achieving food security, but because farm yields are improving fastest in favourable weather, the stakes for having such weather are rising (AFP, 2014).

"In other words, the negative impacts of hot and dry weather are rising at the same time that climate change is expected to bring more such weather."

Extreme and unpredictable weather will affect crop yields and it is estimated that agricultural yields in Africa alone could decline by more than 30% by 2050 (Juma, 2010). Climate change affects the global hydrological cycle in many ways, and these changes have serious implications for agricultural production and food security (Rosegrant, Ringler, & Zhu, 2009). The adverse effects of climate change on freshwater systems exacerbate the negative impacts of other stresses, such as population growth, changing economic activity, land-use change, and urbanisation.

Agricultural productivity depends largely on the temporal and spatial distribution of rainfall and availability of water. Changes in the volume, timing, and intensity of rainfall (a major consequence of climate change) can damage crop growth, disrupt food production and threaten food security (Rosegrant, Ringler, & Zhu, 2009). More than the impact of mean changes in climate, changes in climate variability and increases in climate extremes, such as floods and droughts, will have particularly detrimental effects on crop yields. Analyses of multiple climate change scenarios indicate that climate change will likely have a slightly to moderately negative effect on crop yields, but crop irrigation requirements would increase, as would overall water stress in many areas dependent on irrigation (Rosegrant, Ringler, & Zhu, 2009). Given the vulnerability of rangelands to water deficits, climate variability and drought may lead to a loss in livestock productivity (Rosegrant, Ringler, & Zhu, 2009). Climate change may also reduce the availability of pastoral and farming lands, resulting from the land degradation caused.

The projected impacts of climate change in South Africa poses serious constraints and challenges for Sustainable Agriculture and Rural Development (SARD) (South African Government, 2008). A recent study undertaken for maize indicates that some of the marginal western areas may become unsuitable for production under current management strategies, while some of the eastern production areas may remain unchanged or increase production levels. South Africa is a net exporter of food, and so climate change would also affect food security in the Southern African region. For example, 50% of the maize (the main staple food) in the Southern African Development Community (SADC) region is produced in South Africa (Financial and Fiscal Commission, 2012). Adverse effects of climate variability and extreme weather conditions in South Africa could therefore destabilise the whole region.

The South African Financial and Fiscal Commission (2012) found that the demise of commercial agriculture due to climate change poses a very real threat to food security. By 2050, commercial agricultural net revenue is predicted to lose 18.3%, which may seem moderate, but predictions for 2080 show that the impacts become more drastic. Across all farmer types, predicted losses in net revenue will be 110% on average, making agriculture unprofitable (Financial and Fiscal Commission, 2012).

South Africa's Climate Change Response Strategy suggests that adaptation measures should include changes in agricultural management practices, such as a change in planting dates, row spacing, planting density and cultivar choice, and other measures, which would counteract the effects of limited moisture (South African Government, 2008). Irrigation is currently used to supplement low levels of precipitation, but this could become very expensive and less effective, providing for conditions of increasing aridity. This would require a phasing out of irrigation farming and a relocation of the production areas eastwards, if practicable. To reduce the risk of famine, marginal production areas could be kept economically viable by, for example, decreasing input costs or planting drought resistant crops, such as sorghum or millet. Alternatively, land use could be changed to grazing. Many current agricultural practices, such as conservation tilling, furrow diking, terracing, contouring, and planting vegetation as windbreaks, protect fields from water and wind erosion and assist in retaining moisture by reducing evaporation and increasing water infiltration. Management practices that reduce dependence on irrigation would reduce water consumption without reducing crop yields, and would allow for greater resiliency in adapting to future climate changes (South African Government, 2008). Such methods include water harvesting. The reduced use of some pesticides could directly reduce greenhouse gas emissions and also reduce water pollution, thus contributing to both adaptation and mitigation. Agricultural management practices that recognise drought as part of a highly variable climate, rather than a natural disaster, should be encouraged. Farmers should be provided with information on climatic conditions, and incentives should be given to those farmers who adopt sound practices for drought management, and therefore do not rely on drought relief funds. Land use planning can be used to identify trends in land use that would be advantageous in the event of climate change. Suitable measures could be incorporated in national agricultural policy (South African Government, 2008).

Other measures would be the reduction of reliance on industrialised mono-cropping and diversification of the range of crops cultivated. This will reduce vulnerability, as well as create jobs and potentially reduce irrigation needs (South African Government, 2008). Development of more and better heat and drought resistant crops would help fulfil current and future national food demand by improving production efficiencies in marginal areas, with immediate effect. Additionally, the maintenance of a variety of seed types in seed banks that preserve biological diversity and provide farmers with an opportunity to make informed choices could be used to counteract the effects of climate change, maintain food security and establish possibilities for profitable specialisation (South African Government, 2008). This should be adopted as a priority and needs to maximise the role of local communities.

5.13.3 Soil degradation impacts on agricultural productivity

The fertility of soil is sustained by high nutrient availability from organic and mineral soil components, good soil structure, high available water content, and microbial or animal communities which facilitate good root and shoot growth (Global Food Security, 2013). Threats to soils include soil organic matter (SOM) decline, acidification, erosion and compaction; all accelerated by intensive cultivation. Biodiversity decline (e.g. soil microbes and soil animals) is affected by all of the above and also climate change. Soil microbes benefit crop production because they decompose organic matter, release nutrients in a plant available form (e.g. nitrogen mineralisation), stabilise soil structure and can control soil-borne pests and diseases (Global Food Security, 2013).

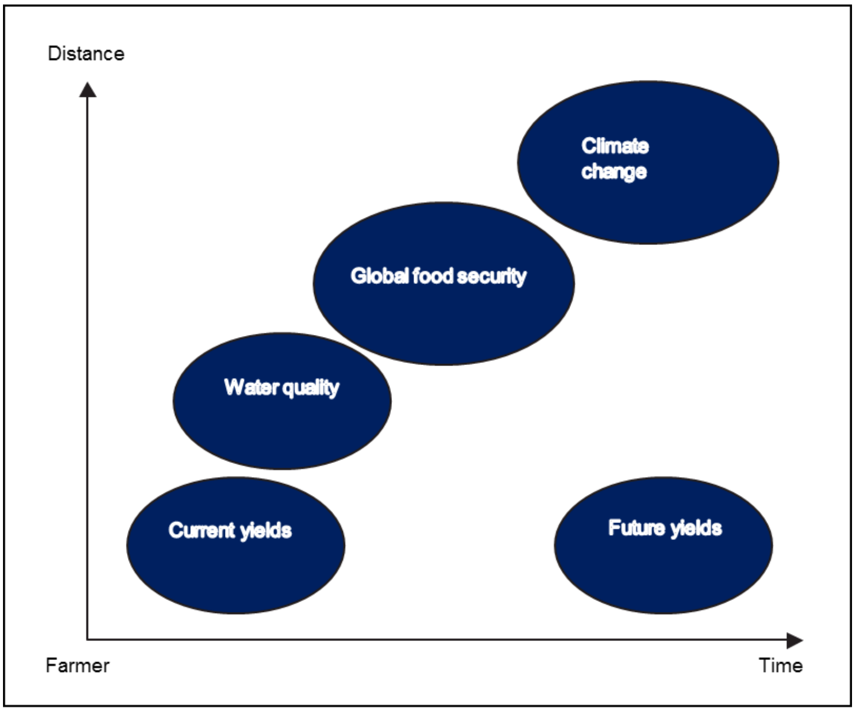
Lindert (2000) defines soil degradation as “any chemical, physical, or biological change in the soil’s condition that lowers its agricultural productivity, defined as its contribution to the economic value of yields per unit of land area, holding other agricultural inputs the same.” Soil quality can be regarded as a synonym for agricultural productivity of the soil. Examples of soil degradation include loss of topsoil through erosion by water or wind, depletion of soil nutrients, loss of soil organic matter, compaction, waterlogging, salinization and acidification. Soil degradation occurs as a result of both natural and human induced processes, such as agricultural production (Wiebe, 2003).

Cropland is highly susceptible to erosion, as frequent cultivation of the soils and the vegetation is often removed before crops are planted (Pimentel, 2006). This exposes the soil to wind and rain energy. Water availability is also affected by erosion: during erosion by rainfall, the amount of water runoff significantly increases, with less water entering the soil, and less water available to support the growing vegetation. Nutrient losses occur when eroded soil carries away vital plant nutrients such as nitrogen, phosphorus, potassium and calcium. Depletion of nutrients lead to stunted plant growth and overall productivity declines. Nutrient deficient soils produce 15% to 30% lower crop yields than uneroded soils (Pimentel, 2006).

Studies suggest that land degradation does not necessarily threaten food security at the global scale, but does pose problems in areas where soils are fragile, property rights are insecure, and farmers have limited access to information and markets (Wiebe, 2003). Differences in land quality contribute to significant differences in agricultural productivity among countries. Some of these differences can be mitigated (e.g., by increasing fertiliser use to reduce or reverse soil nutrient depletion in Sub-Saharan Africa), but others may not be reversible at reasonable economic or environmental cost. For example, potential yield losses to erosion estimated in the soil science literature average 0.3% per year across regions and crops. These estimates focus on biophysical relationships in the absence of behavioural response - actual yield losses will be lower to the extent that farmers act to avoid or reduce these losses (Wiebe, 2003).

Land degradation’s effects on productivity are, thus, likely to be more severe in some regions and local areas, due to a combination of resource factors (terrain, soils, and precipitation) and economic factors (poverty, tenure insecurity, and lack of infrastructure). Land degradation’s impacts on productivity may affect food security in some areas both through losses in aggregate production (and thus higher food prices for all consumers) and through losses in income for those who derive their livelihoods from agricultural land or agricultural labour (Wiebe, 2003).

Figure 5.12 depicts the temporal and spatial effect of land degradation. The mean loss in annual yield per ton of soil erosion for various crops, in various continents is provided in Table 5.9. The function between yield and land quality typically follows an s-curve.



(Wiebe, Resources, Technology, and Public and Private Choices, 2001)

Figure 5.12 Land degradation effects over space and time

Table 5.9 Mean loss in annual yield per ton of soil erosion

Region	Crop	Experiments	Mean yield	Mean yield loss per ton of soil erosion	
		Number	*Tons per hectare*	*Kg per hectare*	*% of mean yield*
Africa	Maize	42	2.6	0.9	0.03
Asia	Maize	4	1.7	0.7	0.04
	Millet	2	0.3	0.1	0.03
	Soybeans	4	0.9	-0.5	-0.01
	Wheat	4	3.0	0.7	0.02
Australia	Potatoes	2	54.1	3.6	0.01
	Wheat	16	1.2	0.5	0.04
Europe	Millet	2	0.3	0.1	0.02
	Potatoes	2	11.4	0.6	0.00
	Soybeans	1	0.6	0.1	0.02
	Wheat	8	3.5	0.2	0.00
Latin America	Maize	15	2.9	1.4	0.05
	Potatoes	1	20.2	0.7	0.00
	Soybeans	4	2.1	0.6	0.03
	Wheat	1	2.1	0.4	0.02
North America	Maize	131	6.2	0.6	0.01
	Potatoes	3	30.5	127.0	0.42
	Sorghum	17	4.2	0.1	0.00
	Soybeans	43	2.1	0.3	0.01
	Wheat	64	2.6	0.4	0.01

Note: Some studies report multiple experiments.

(den Biggelaar, Lal, Wiebe, & Breneman, 2004)

Degradation of soils can, however, be reversed to deliver multiple benefits, including improved nutrient and water management, soil organic carbon content, natural pest and disease regulation and reduced soil erosion (UNEP, 2013). This significantly increases the efficiency of the use of inputs (e.g. fertiliser, pesticides and herbicides), thereby simultaneously increasing food productivity, reducing off-farm impacts and increasing resilience to climate change.

5.13.4 Transportation activity impacts on agricultural productivity

Transport is a critical element in agricultural productivity (Were-Higenyi, 2010). Infrequent, expensive or poor quality transport and storage services increase product costs, damage goods and increase crop deterioration. Transportation is a major constituent of the final market price of produce, and high prices affect both the producer and the consumer. For consumers, reducing transport costs can reduce the price consumers pay. Should food become unaffordable, it becomes inaccessible and food security ceases to exist. On the producer side, transport costs vary according to factors such as commodity type, distance, efficiency, perishability, but typically constitute 3.5% to 25% of the market price, of which farmers only receive 30% to 50% of final market price and difference goes on transport costs (Were-Higenyi, 2010). If transport supply fails producers, large losses can be lead. It is estimated that in Tanzania, typically 10% to 40% of the harvest remains stranded and as much as 89% of this is due to inadequate supply of transport. Improved access roads and transport leads to increased income and food security.

5.13.5 Water quality impacts on agricultural productivity

Irrigated agriculture is, globally, the main source of water withdrawals, accounting for around 70% of all the world's freshwater withdrawals (Rosegrant, Ringler, & Zhu, 2009). The development of irrigated agriculture has boosted agricultural yields and contributed to price stability, making it possible to feed the world's growing population. Rapidly increasing non-agricultural demands for water, changing food preferences, global climate change, and new demands for biofuel production place increasing pressure on scarce water resources. Challenges of growing water scarcity for agriculture are heightened by the increasing costs of developing new water, increasing soil degradation, increasing groundwater depletion, increasing water pollution, the degradation of water-related ecosystems, and wasteful use of already developed water supplies (Rosegrant, Ringler, & Zhu, 2009). Land degradation reduces not only land productivity, but it can also reduce water-use efficiency. Water pollution reduces agricultural production and threatens the health of fish, other aquatic life, and humans. Salinity is one of the largest water quality problems facing the agricultural sector.

5.13.6 Summary of the links to food security

Figure 5.13 summarises the links between climate change, agriculture, hydrology and other transport-related environmental impacts to food security, as discussed in section 5.13.

5.14 Summary of transport related environmental impacts

5.14.1 First order impacts

Each component of the transportation system contributes to many different first order impacts. Air pollution, water pollution and soil pollution appear to be the most severe impacts, as several different sources produce the same impact. From the diagram (Figure 5.14) it can be detected that transport activities generate the most impacts, followed by the supply of infrastructure, the supply of energy and lastly the supply of vehicles (in diminishing order). Please take note that the diagram is not intended to be studied line by line (though this would be possible), but rather to provide an overview of the strongest links between components and to showcase the reduction in tractable impact quantity as the impacts become more indirect.

Transport activity chiefly generates air pollution, contributes to the greenhouse effect and is solely responsible for noise pollution. The noise pollution during infrastructure construction is too short lived to be comparative. Infrastructure is, however, the key contributor to water and soil pollution (exacerbated by vehicle maintenance activities utilising the infrastructure). The main impacts due to energy supply are emissions, both in terms of air pollution and greenhouse gases.

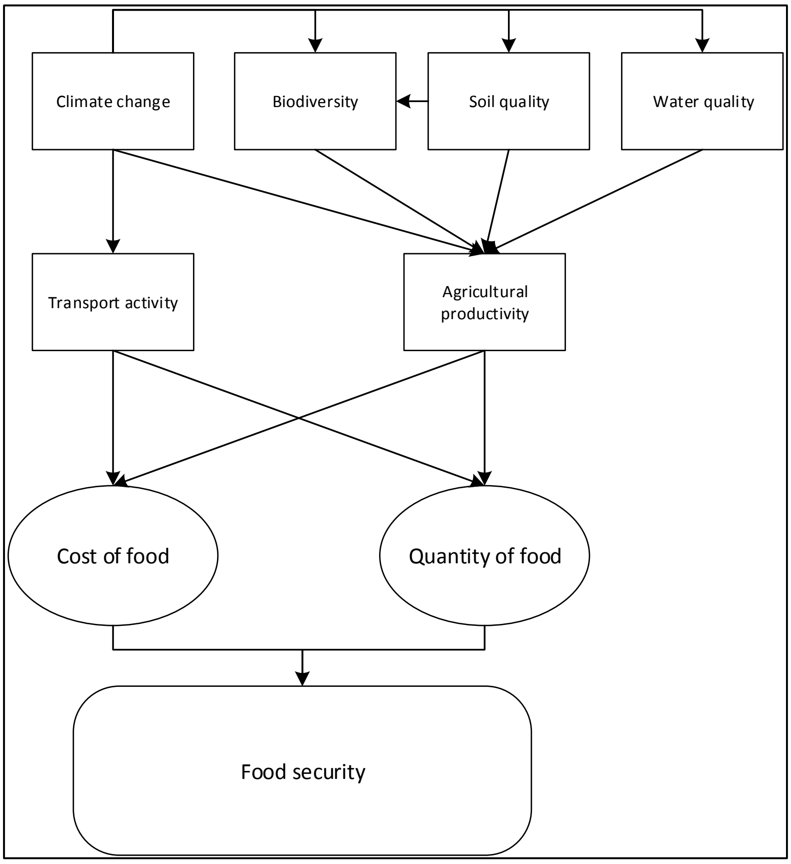


Figure 5.13 Summary of links to food security

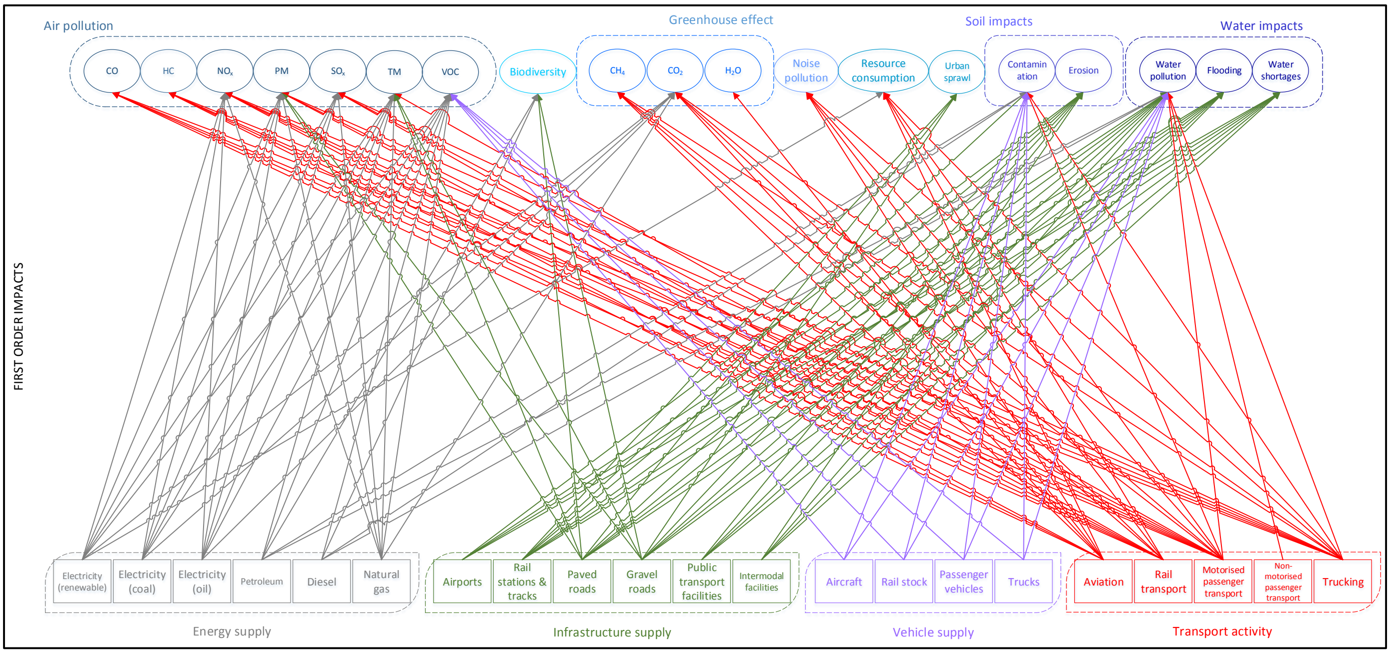


Figure 5.14 First order environmental impacts from transportation

5.14.2 Second order impacts

Some first order impacts are repeated, but that is because that impact occurs as a consequence of other first order impacts, so the impact is both directly (first order) and indirectly (second order) effected. These impacts, both directly and indirectly attributable to transportation, are indicated with dashed lines (Figure 5.15). The most dominant second order impact can be seen to be health impacts. Air, water and noise pollution contribute greatly to health impacts. Second to health impacts, are impacts on climate change and impacts on crops.

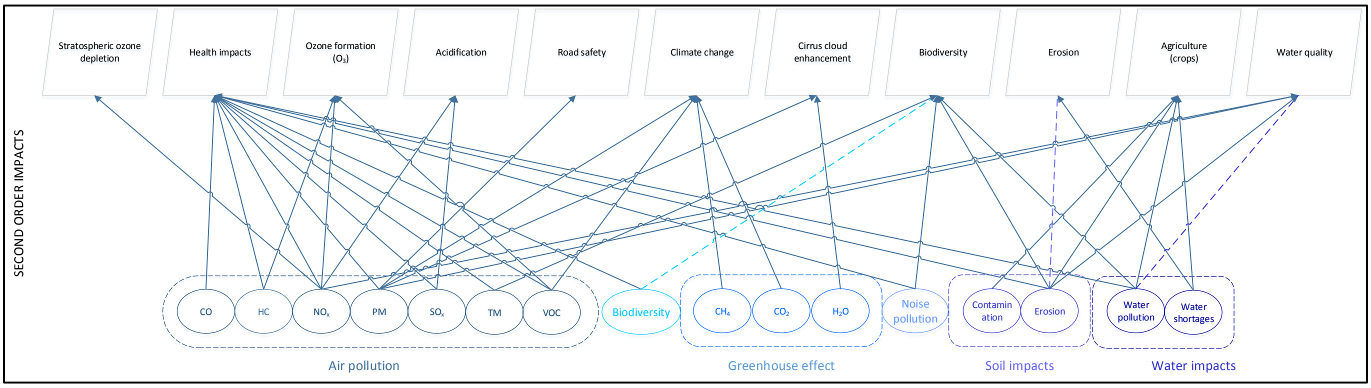


Figure 5.15 Second order impacts resulting from first order impacts

5.14.3 Third order impacts

Some second order impacts result in the contribution to impacts that have already been generated by other sources (indicated by the dashed lines in Figure 5.16). These include: biodiversity, health impacts, water quality, climate change, agriculture and soil degradation (erosion). Many third order impacts also influence each other, but here the link to transportation as a source becomes tenuous and double counting becomes a possibility.

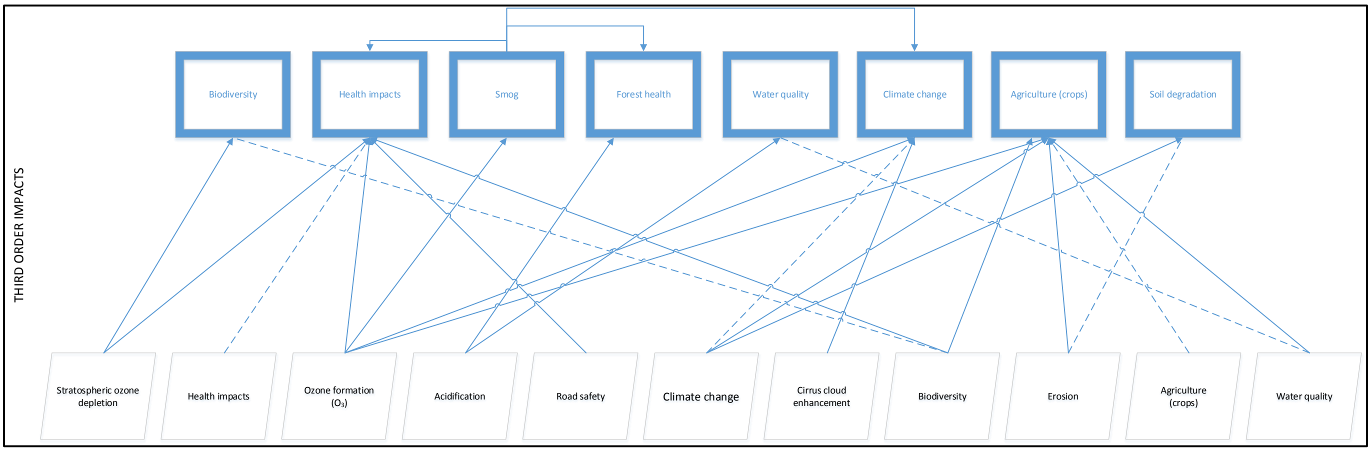


Figure 5.16 Third order impacts resulting from second order impacts

6. Transportation impact assessment in the Letaba district

6.1 Generalised methodology to assess localised transport impacts

There are strong geographical properties associated with sustainability impacts – some impacts occur within close proximity to their point of origin (localised) and some can occur in a seemingly unrelated geographical location, somewhere on the other side of the planet (globalised) or even affect the entire planet (globalised). At this point, it is important to reiterate that the purpose of this study is to determine only the localised impacts resulting from transport development in the study region. Localised impacts can be generated in one of two ways – in the direct vicinity of a fixed node, or in the direct vicinity along an entire transportation route. Air transport impacts can be split into nodal, as well as en route-based impacts. Intermodal facilities, in turn, only generate node-centred impacts. Road and rail transportation typically generate impacts in an approximate uniform fashion along the entire length of the routes travelled.

When determining the cumulative impacts generated around a specific node, a ratio of the average impact per node of a certain type is multiplied by the number of nodes of that type within the study area. This can be done for all the impacts to be assessed. Every impact type will have a certain radius around the node which is affected by the impact.

It is important to include not only the impacts generated by the physical transportation activity, but also the impacts generated through the enabling of transport, when calculating transport related sustainability impacts. Adequate infrastructure provision, access to energy sources and provision of vehicles to effect the transportation are the key enablers of transportation activity. It is thus important to include any impacts generated by the provision of infrastructure, the supply of energy and the supply of vehicles in the area in a transport impact assessment endeavour. In this study, only the localised impacts generated by these enabling forces are taken into account.

Impacts generated from energy supply are both node-based and route-based. The node-based impacts are those generated around electric power stations during power generation activities, those generated during the refining process at liquid fuels refineries and those generated by the storage and distribution of liquid fuels at filling stations. The route-based impacts are attributed to the physical transportation of liquid fuels between refineries and filling stations. In essence, liquid fuels is merely another commodity class accounted for when the transport activity (propulsion) impacts are estimated.

In terms of vehicle supply, there can be impacts generated during the vehicle manufacturing process. Should there be no vehicle production in the region (as is the case in the Letaba catchment), the localised vehicle manufacturing impacts fall outside the study boundary. Further to this, there is a strong temporal property to vehicle production impacts. The typical vehicle has long life-span, ranging anywhere between five years and fifty years. If these impacts were to be included in an assessment, a discounting over the life-span of the vehicle needs to be taken into account.

To estimate the impacts generated along the entire route travelled, the total volume of transportation on that particular route (expressed in terms of both the number of vehicles or entities travelling and the distance travelled by said vehicle or entity – for example: tonne-kilometre or car-kilometre) is multiplied by the impact factor on that route. The impact factor (expressed as a ratio of impact level per unit of transportation volume) is often affected by the quality of the infrastructure along the route. There can, thus, be different impact factors for the same transportation impact over various infrastructure development scenarios.

As for the volume of transport required along the route, this is mainly affected by the level of economic development in the areas along the route; there is a direct relation between economic development and transport generated impacts. Agricultural and mining developments load more freight onto the network on their respective dominant routes. Development in the tourism sector results in increased passenger transportation on the network links providing access to the tourism destinations. It should be mentioned that any form of economic development is also assumed to induce higher volumes of passenger transport, especially around the development nodes. This is due to job opportunities being unlocked, resulting in greater volumes of commuting and higher disposable income levels for the local population resulting in more recreational travel and more private (small-scale) commercial activities taking place.

Infrastructure development can, however, also impact transport volumes, as a lack of adequate infrastructure (be it due to non-existence or poor conditions rendering the route unfavourable when compared to longer, alternate routes) can result in greater travel distances, which increases the passenger-kilometre or tonne-kilometre figures.

Figure 6.1 depicts this generalised impact calculation model and highlights the input data and model parameters required to perform such an.

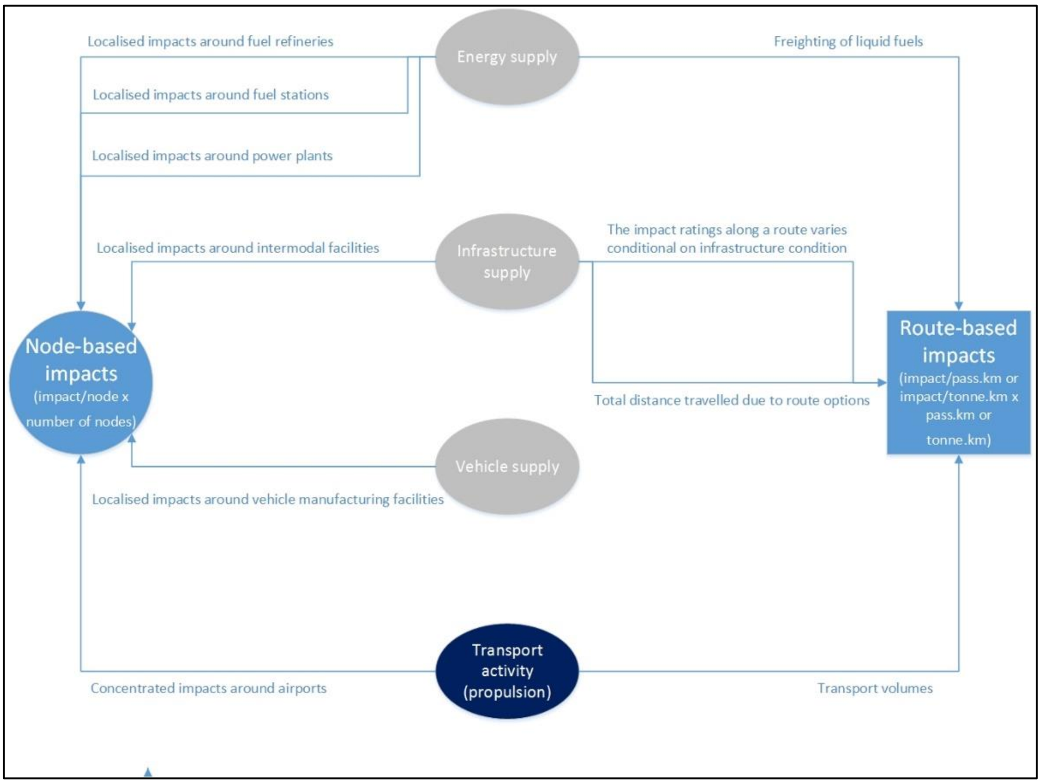


Figure 6.1 Schematic of the transport impact assessment model

Please note that a route, as mentioned here, is seen to encapsulate a physical transportation route for a particular mode. The impact estimates have to be calculated utilising the methodology described for each route travelled by every mode. Once this is complete, the impacts can be aggregated to get a sense of network-wide impacts.

6.2 Letaba transportation impact assessment model configuration

The approach followed in this assessment is to determine the relative differences between potential development scenarios and between two climate change simulations, in order to ultimately contrast and compare the total network-wide impacts to be expected over several potential future development paths. These future development scenarios and the climate change simulations are discussed in sections 6.2.3 and 6.2.4 of this report, respectively.

Following this approach implies that only routes and nodes that are changed in a particular scenario (with reference to the base state modelled in scenario I) need to be modelled. All other routes and nodes remain constant in terms of transport activity, hence there is no relative change to account for, which means it can be omitted from the analysis.

6.2.1 Transport enablers in the Letaba catchment

As only localised impacts are of interest, it needs to be established which transport enablers are, consequently, relevant to the localised transport impacts assessment calculations.

6.2.1.1 Infrastructure supply impacts

Infrastructure development is expected to be one of the main drivers of change in the region going forward. The regional development scenarios aim to account for uncertainty in terms of exactly what the level of infrastructure development will be and, hence, every scenario has a particular outlook for infrastructure in the area. The particular infrastructure development configuration for each scenario is discussed in section 6.2.3.

6.2.1.2 Energy supply impacts

ESKOM, South Africa's only electricity utility, lists four power plants in the Limpopo Province. They are the Matimba Power Station (GPS: 23°40'06"S; 27°36'38"E) near Lephalale, Medupi Power Station (GPS: 23°42'S; 27°33'E) near Lephalale, Soutpan Solar Park in the Waterberg region and Witkop Solar Park (GPS: 24°2.5'S; 29°21.7'E), which is still under construction. None of these reside within the study area, and, therefore, no electricity supply local environmental impacts are generated.

Similarly, there are no liquid fuel refineries located within the study area boundaries. All liquid fuels are freighted into the area from other parts of the country. The localised social and environmental impacts from liquid fuel supply that are to be included, are generated both en route by the freight trucks transporting the fuels and in the local vicinity of the fuel stations (nodes) where the fuels are stored and distributed. The impacts resultant from the freighting activity is accounted for under the overall transportation activity volumes and should not be double counted by inclusion in this category. This leaves only the node-based liquid fuel supply impacts to be considered.

According to data provided by the eFuel website (http://www.efuel.info), filling stations are concentrated in the urban developments in the region (Giyani, Tzaneen and Phalaborwa) (Figure 6.2). In Figure 6.2, the pink outline shows the border of the Letaba catchment. The white line is the border of the Kruger National Park. Red markers indicate the main filling stations in the area. It is not foreseen that any changes to the distribution of filling stations occur in the respective development scenarios and, therefore, there will not be a difference in the impacts generated between scenarios, implying that this element, too, can be excluded from further analysis.

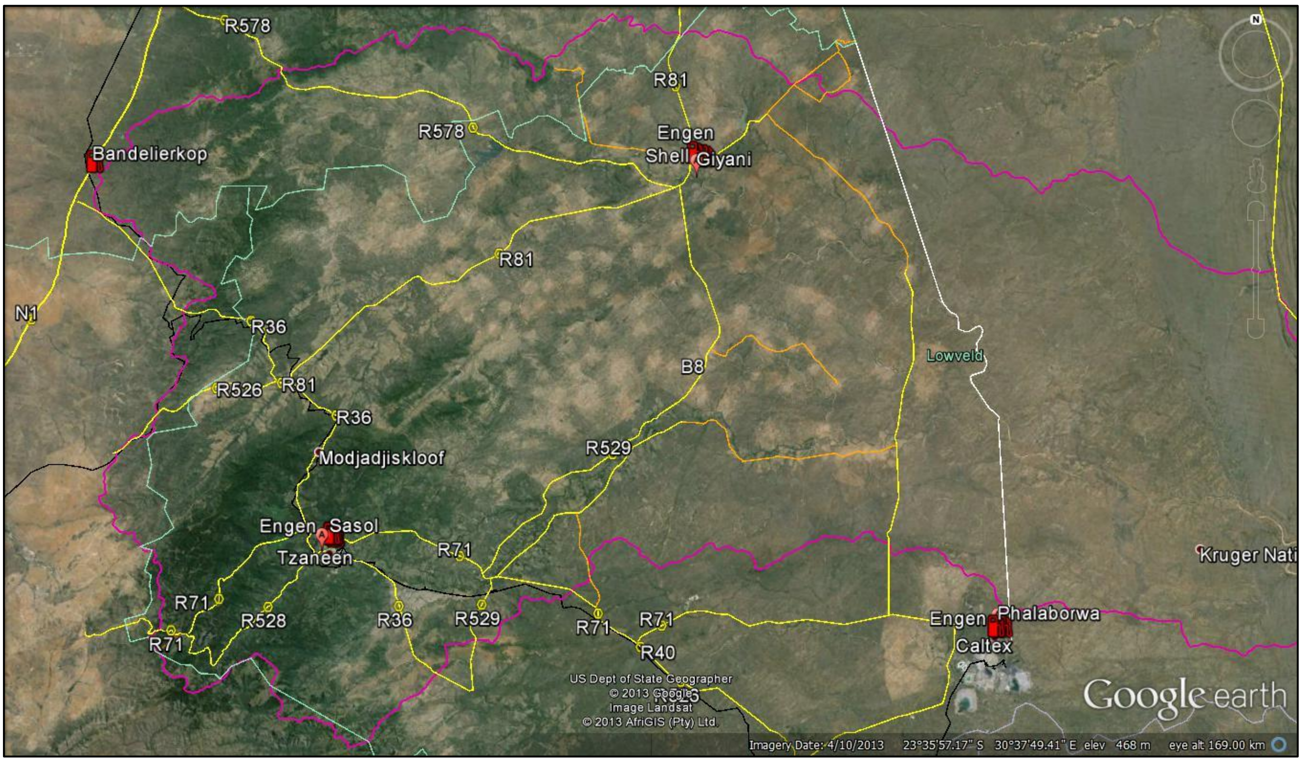


Figure 6.2 Fuel supply locations within the study area

6.2.1.3 Vehicle supply impacts

There are no vehicle manufacturing facilities (neither for motorcars, trucks, rail rolling stock, nor aircraft) located within the study area, and, hence, no localised impacts can be measured as a result of the supply of vehicles to enable transportation in the region.

6.2.2 Potential localised environmental impacts

Figure 6.3 showcases the localised environmental impacts potentially relevant to the study area. When comparing Figure 5.14, it is noticed that all energy supply and vehicle supply related impacts have been eliminated. Further to this, a number of first order impacts have been excluded as well. These include: volatile organic compounds (VOC), greenhouse effect impacts, resource consumption and flooding.

VOCs are generated during energy and vehicle supply actions only, and, as none of these pertain to the study area, VOCs can be omitted from the study. Greenhouse gases are gases that remain in the earth's atmosphere for a substantial amount of time. They do, however, not remain stationary, and it is virtually impossible to attribute localised climate based impacts to any direct source of emissions. These impacts are, thus, not deemed localised first order impacts, despite physically being emitted locally, initially. The resources referred to as resource consumption impacts are mainly imported oil and coal mined in other parts of the country. As such, local resource consumption is not affected. Finally, flooding impacts (as construed in the impact link model in Figure 5.14) are related to the volume of infrastructure within the study area. It is not foreseen that the overall physical transportation network will change in terms of volume in any of the scenarios (new routes are not built, existing routes are rather upgraded for increased utilisation) and, hence, flooding is not included as a first order impact to consider.

As a consequence of the elimination of transport impact drivers (energy and vehicle supply), as well as some first order impacts, the resulting second and third order impacts are not to be considered. Second order impacts thus excluded from further analysis are climate change and cirrus cloud enhancement. Stratospheric ozone depletion, ozone formation and acidification are excluded as none of them are classified as strictly localised impacts. Biodiversity (as third order impact due to stratospheric ozone depletion) is also effectively excluded from further analysis. In a similar vein smog, forest health, water quality (as third order impact due to acidification), climate change and soil degradation (resulting from climate change) can be eliminated as localised impacts.

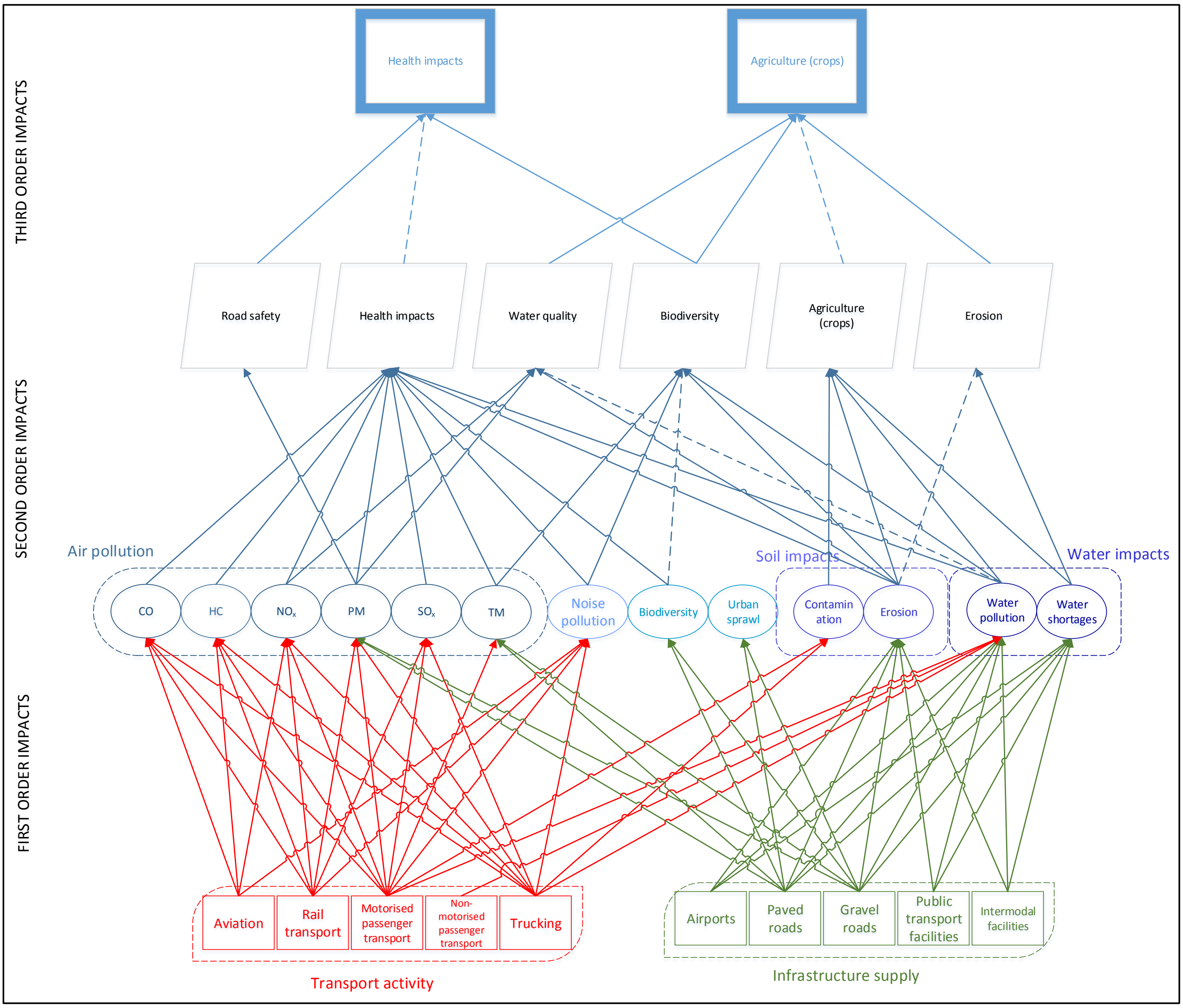


Figure 6.3 Localised environmental impacts to be included

6.2.3 Regional development scenarios

The regional development scenarios to explore in this study are developed, based on the quadrant method (Figure 6.4). From the discussion so far, it is clear that there are two key forces that will influence the development of and quantum of impacts generated by transportation in the region going forward. These two forces are: economic development (shown on the horizontal axis) and infrastructure development (shown on the vertical axis). This forms the basis for the development of four potential regional development scenarios. It should be noted that there can be positive reinforcement between the two driving forces (e.g. a growing economy could stimulate infrastructure development, or a lack of infrastructure could hinder economic development), but it is entirely possible that the two forces develop in opposite directions. This is due to the fact that the decision making on and management of these forces are decentralised and, thus, do not reside within one entity. Additionally, the funding to promote initiatives stimulating economic and infrastructure development does not flow through a single channel and is often subservient to a variety of alternate management initiatives.

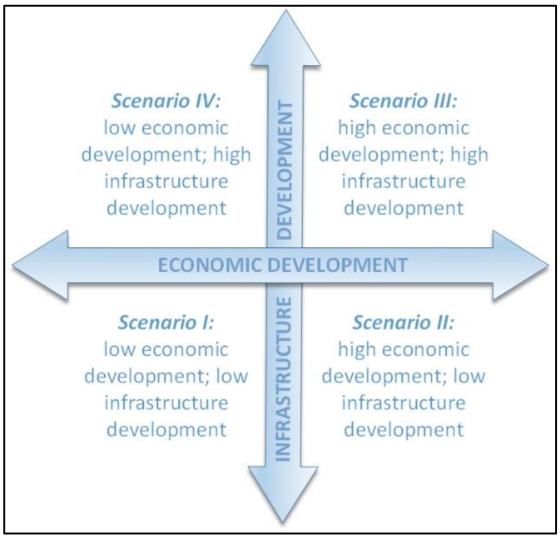


Figure 6.4 Regional development scenarios

The idea behind a scenario analysis approach is to paint a full picture of the contrast between various potential development scenarios. This allows decision makers to become aware of the potential impacts that their decisions might have, despite the uncertainty about which development path will actually realise. The development path followed might be out of the decision maker's direct control, but at least they can be cognisant of the expected impacts, regardless of which pathway actually unfolds. Because extreme events are modelled, there is no future date on which the scenarios are based, extreme values deemed realistically achievable in favourable conditions within the next 36 years (to 2050) are used.

6.2.3.1 Scenario I – low economic development; low infrastructure development

In scenario I, it is assumed that there is no change to the transport volumes within the region, as there is no change to the state of the economy. In terms of infrastructure, it is also assumed that there is no investment and upgrade to the current infrastructure. The majority of roads thus remain gravel and in poor condition and there are almost no formal public transport facilities. Scenario I essentially becomes a reference point for all other scenarios to be measured against. As this scenario is a reference scenario, a basic network configuration resembling the current state of affairs in the region is required.

To this end, 2013 total transportation volumes as published by Roads Agency Limpopo (www.ral.co.za) were obtained for each road segment altered in any of the other scenarios. The Roads Agency Limpopo data covers all gravel and paved provincial roads and is provided as annual average daily traffic counts. To supplement this dataset, South African National Roads Agency (SANRAL, www.sanral.co.za) data of 2010 annual average daily traffic counts on national roads were converted to 2013 equivalents and included. The SANRAL data also included freight and passenger vehicle splits for each segment in their network. Similar freight versus passenger transport volume splits were assumed for the rest of the network. Google Earth and Google Maps were utilised to determine the various lengths of road segments relating to a particular traffic count. Utilising this database, it is possible to determine the total passenger vehicle-kilometres and freight vehicle-kilometres travelled in the study region in 2013. Additionally, maps obtained from the Roads Agency Limpopo website (included in section 2.2.1 of this report) informed on whether a segment referred to a paved or gravel road. A list of all road segments included in the model is included in Appendix A.

6.2.3.2 Scenario II – high economic development; low infrastructure development

Similar to scenario I, it can be assumed that there is no improvement on the current state of the infrastructure in the region. A high economic development scenario, in turn, is meant to represent the situation where the proposed economic development initiatives discussed in section 3.1 come to fruition. These scenarios are subdivided into four sub-scenarios:

A – Only agricultural development takes place. Tourism and mining levels are assumed unchanged.

B – Only mining sector development takes place. Agriculture and tourism levels are assumed unchanged.

C – Only tourism sector development takes place. Agriculture and mining levels are assumed unchanged.

D – All economic sectors develop simultaneously.

In all of these sub-scenarios, general economic development is expected to stimulate work and shopping trips by the local communities. In particular a new shopping centre to be built in Tikiline (Tzaneen) will generate more local traffic (it is assumed local shopping trips will double within a 20km radius of this node). To model these shopping trips, the number of passenger vehicles on segments linking to the shopping centre is increased in relation to the portion of trips that are shopping related (obtained from the National Household Travel Survey data (Department of Transport, 2003)). The total number of shopping trips are doubled and the extra vehicles are added to the relevant segments' total passenger volumes.

6.2.3.3 Sub-scenario A – agricultural development

Agricultural development implies that the volume of agricultural freight transport increases threefold (as mentioned in section 3.1.1). This affects key transport routes in Thulamela, Makhado, Greater Tzaneen, Greater Letaba and Greater Giyani. As agricultural produce is mainly transported to Gauteng, key roads connecting the study region to the N1 (the R71, R36, R526, R81 and the R578) are most heavily affected. It is assumed that between 1.1% and 8.7% of all freight transported on these routes are agricultural produce. This is equivalent to the contribution of agriculture to the local gross domestic products (GDPs) of each district municipality (Mopani District Municipality, 2013). Where agriculture is expected to grow, work trips by the local residents is expected to grow in line with the development. Passenger transport volumes related to work trips (again derived from the National Household Travel Survey data (Department of Transport, 2003)) are also expected to triple on segments connecting residential areas to areas of agricultural development.

Less than one percent of the total rail freight transported on the Tzaneen – Letsitele rail line is citrus fruit. A tripling of this is deemed negligible and excluded from further analyses.

There are plans to expand forestry activities in the region, and a 10% increase of forestry related (i.e. including beneficiation produce) freight is expected. This will mainly impact the R528 and R71 from Tzaneen to Moria. The amount of forestry related shipments on the Tzaneen – Letsitele line is also too small to be of importance. Similarly, it is assumed that the amount of air freight related to agriculture in the region is negligible.

6.2.3.4 Sub-scenario B – mining development

Mining development implies that freight volumes resulting from the mining activities in the area (this includes beneficiation) are doubled over time. The resultant impact is an increase in both road and rail freight. In the Ba-Phalaborwa district, 60% of freight is related to mining activities at present. Other districts affected by mining sector growth are Thulamela, Makhado and Greater Tzaneen. The only key road affected that falls within the study area is the R71 between Tzaneen and Phalaborwa. To determine the number of freight vehicles on these segments that are specifically related to mining, it is assumed that it is proportional to the percentage contribution (6.8%) of mining to Tzaneen's overall GDP (Mopani District Municipality, 2013).

On the rail side, mining freight is the key commodity transported on the Groenbult - Kaapmuiden line. However, most of this resides on the Phalaborwa link, which falls outside the study area.

6.2.3.5 Sub-scenario C – tourism development

Tourism development implies that the number of tourists on each tourist route is doubled in this scenario. The main tourist routes in the area are the connections to the Kruger National Park. These include: the R71 to the Phalaborwa gate, the R81 through Giyani to Punda Maria gate and the D3641 to the new Shangoni gate. It is expected that the Shangoni gate will attract approximately half the tourist traffic from Phalaborwa and Punda Maria alike. The assumption is made that, traditionally, 70% of traffic headed for the Northern half of the KNP enters via the Phalaborwa gate and 30% via Punda Maria (as a result of Punda Maria's relative isolation). In this scenario, it is assumed that the Shangoni gate will attract 50% of all vehicles, whilst Punda Maria serves 20% and Phalaborwa now 30%. Visitation statistics for the Kruger National Park were found in their annual report (SANParks, 2013). The amount of unit and camping site nights sold were assumed to be a proxy for the number of cars entering the park.

Another important tourist route is the road connecting Mooketsi to Modjadjiskloof. In the Vhembe district, the main tourist route in the study region (although not as popular as the other routes mentioned) is the R578 between Elim and Giyani. On each segment, the amount of passenger traffic related to tourism was assumed to be in line with the tourism sector's contribution to municipal area GDP figures (9% in Tzaneen, 10.3% in Giyani and 9.7% in Letaba) (Mopani District Municipality, 2013). The links between the economic drivers and road segments affected by change is shown in the table in Appendix A.

The rail line in the study area is currently not developed as a tourism oriented transportation service.

6.2.3.6 Sub-scenario D – comprehensive economic development

All the developments included in sub-scenarios A, B and C are assumed to occur simultaneously.

6.2.3.7 Scenario III – high economic development; high infrastructure development

This scenario can again be split into four sub-scenarios, as in scenario II, to account for a range of economic development scenarios. The difference is that in this scenario, the various economic growth scenarios are paired with extremely high levels of infrastructure development.

This high infrastructure scenario is an extreme scenario where all key roads in the region are tarred and in a good condition and public transport facilities are upgraded. Some of the key roads that are included are the main economic and freight corridors contained within the study region and roads earmarked for upgrades by the local authorities are listed in Table 6.1. Additionally, in this scenario, new public transport facilities are provided and informal facilities are upgraded to formal facilities with shops and better infrastructure. These facilities stimulate an increase in localised traffic around them (a doubling of volume is assumed). It is also expected that better service delivery can be achieved if more rural roads are tarred, providing access to scheduled buses. In Ba-Phalaborwa there are nine informal taxi facilities that will be upgraded, ten in Giyani, seven in Greater Letaba, twenty in Greater Tzaneen and approximately ten throughout Thulamela and Makhado (Mopani District Municipality, 2013). Moreover, there are approximately three bus ranks to be upgraded in Thulamela and Makhado, one in Tzaneen, Giyani, Phalaborwa and Modjadjiskloof, each (Mopani District Municipality, 2013). The proportion of minibus taxi and bus traffic on the main routes served by these facilities are based on the National Household Travel Survey modal split statistics (Department of Transport, 2003).

In terms of rail infrastructure, no expansion of the current railway line is proposed for the foreseeable future in this region. Aviation infrastructure, however, can expand if Giyani airport is upgraded and commercial traffic is attracted to it. Should the Giyani airport be upgraded as proposed for the high infrastructure development scenarios, the R81 and D3641 will probably receive more tourists driving between the airport and the Kruger National Park. Additionally, this airport could service tourism needs related to the Tzaneen Dam, Magoebaskloof and Ebenezer Dam along the R81 or R529. It is assumed that one 50 seat flight will visit Giyani airport per day. The impacts related to air traffic activity is not strictly confined to the study region, and are therefore omitted. Only the impacts due to increased passenger tourism traffic along the routes mentioned are included.

Table 6.1 High infrastructure development scenarios: roads to be upgraded

Key roads to be upgraded from gravel to pavement or to good condition			
R36 (from Morebeng to Modjadjiskloof)	R529 (from Giyani to Tzaneen)	D3634 (local road around Giyani)	D3843 (district road)
R71 (from Moria to Phalaborwa)	R578 (from Giyani to Elim)	D3778 (local road around Giyani)	D3187 (district road)
R81 (from R524 through Giyani to the R526)	D3810 (from Giyani to Phalaborwa)	D3753 (local road around Giyani)	D3180 (district road)
D3641 (road to Shangoni gate)	D3799 (road to Muyexe)	D3718 (local road around Giyani)	D3837 (district road)

6.2.3.8 Scenario IV – low economic development; high infrastructure development

In the low economic development scenarios, it is assumed that there is virtually no growth in the key economic activities (agriculture, mining and tourism) within the study area. This implies that there is no additional freight, tourist or commuter traffic on the network. The same infrastructure development does, however, take place and public transport facilities, as well as gravel roads are upgraded. There is no upgrade to the Giyani airport, as there is no increased tourism demand to stimulate such capital expenditure.

6.2.3.9 Scenario summary and comparison

Table 6.2 depicts the changes in transportation volumes and/or infrastructure proposed in each of the scenarios.

Table 6.2 Summary of volume and infrastructure changes included in each regional development scenario

		Scenario I	Scenario II:A	Scenario II:B	Scenario II:C	Scenario II:D	Scenario III:A	Scenario III:B	Scenario III:C	Scenario III:D	Scenario IV
PASSENGER TRANSPORT VOLUME	Shopping trips increase		✓	✓	✓	✓	✓	✓	✓	✓	
	Work trips increase (agriculture)		✓			✓	✓			✓	
	Tourism trips increase				✓	✓			✓	✓	
	Giyani airport one flight per day								✓	✓	
FREIGHT TRANSPORT VOLUME	Agricultural freight increase		✓			✓	✓			✓	
	Forestry freight increase		✓			✓	✓			✓	
	Mining freight increase			✓		✓		✓		✓	
INFRASTRUCTURE	Paved roads upgraded to good condition						✓	✓	✓	✓	✓
	Gravel roads upgraded to pavement						✓	✓	✓	✓	✓
	Informal taxi ranks upgraded						✓	✓	✓	✓	✓
	Informal bus ranks upgraded						✓	✓	✓	✓	✓
	Giyani Airport upgraded								✓	✓	

6.2.4 Estimating the impact of climate change in the Letaba catchment

Climate change is a major threat to sustainable development and development in Africa and the achievement of Millennium Development Goals. Africa is the continent least responsible for climate change and, at the same time, especially vulnerable to the effects. This overall context calls for clear evidence of effort and success in reducing GHG emissions wherever possible, whilst at the same time recognising Africa's development needs (Haq, et al., 2011).

In this study, the impact of climate change on the sustainability of planned developments in the Letaba catchment will be explored by running two simulations (where all scenarios are run under the same simulation assumptions) – one based on the assumption that the earth's climate stays as we know it today and have known it in the past. In this case one can extrapolate from historical trends and only the changes in the proposed scenarios (laid out in section 6.1) are assumed to occur. The second set of scenario assessments will be under the assumption that the climate predictions published by the CSIR (2010) and discussed in section 4.4.4 are correct and materialise. The forestry, agriculture and tourism sectors are mainly affected by climate change in the region. Mining sector growth and infrastructure development are not affected.

Data from climate change models developed over time by the CSIR in South Africa (Engelbrecht, et al., 2011; Engelbrecht, Rautenbach, McGregor, & Katzefey, 2002; Engelbrecht F. , 2005) was utilised in ArcSWAT to simulate the influence of climate change in the Letaba catchment between 2013 and 2050.

ArcSWAT is an ArcGIS extension for the Soil and Water Assessment Tool (SWAT) model developed by Arnold et al. (1998). SWAT is a river basin, or watershed, scale model developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large, complex watersheds with varying soils, land use, and management conditions over long periods of time. The model is physically based and computationally efficient, uses readily available inputs and enables users to study long-term impacts. Under the auspices of the EAU4Food project (http://www.eau4food.info/) a SWAT model for the Letaba catchment was set up.

Figure 6.5 (produced by ArcSWAT) depicts the current hydrological state of affairs, used in this study to represent the 'no climate change' simulation. In contrast, Figure 6.6 shows the 'climate change' simulation state of affairs, based on the CSIR climate change forecast data. From these figures it is evident that average evaporation increases and average precipitation increases slightly. Surface runoff is reduced in the climate change simulation configuration, likely exacerbating the effects of pollution (soil and water) in the region. The SWAT model projects an 8.9% increase in average temperatures, a 1.4% reduction in total precipitation in 2050 specifically, a 20.2% increase in crop yields and a 22.2% increase in water yield per sub-basin.

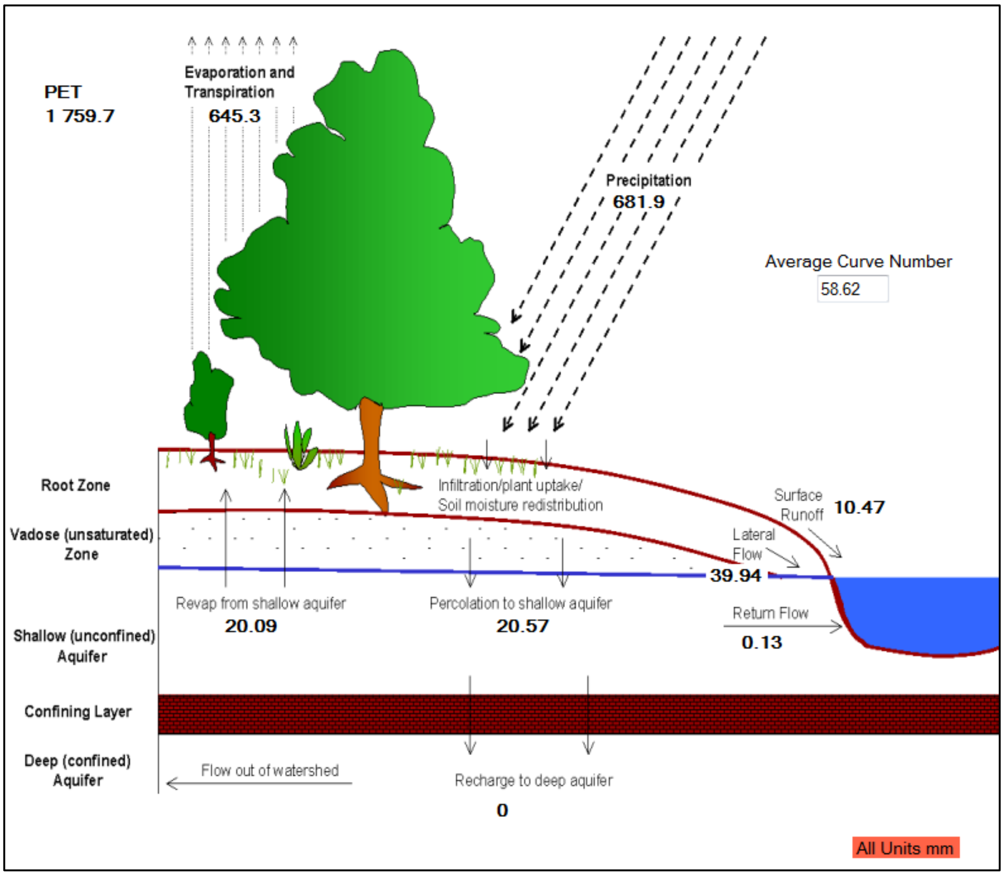


Figure 6.5 ArcSWAT scenario with 2013 climate data

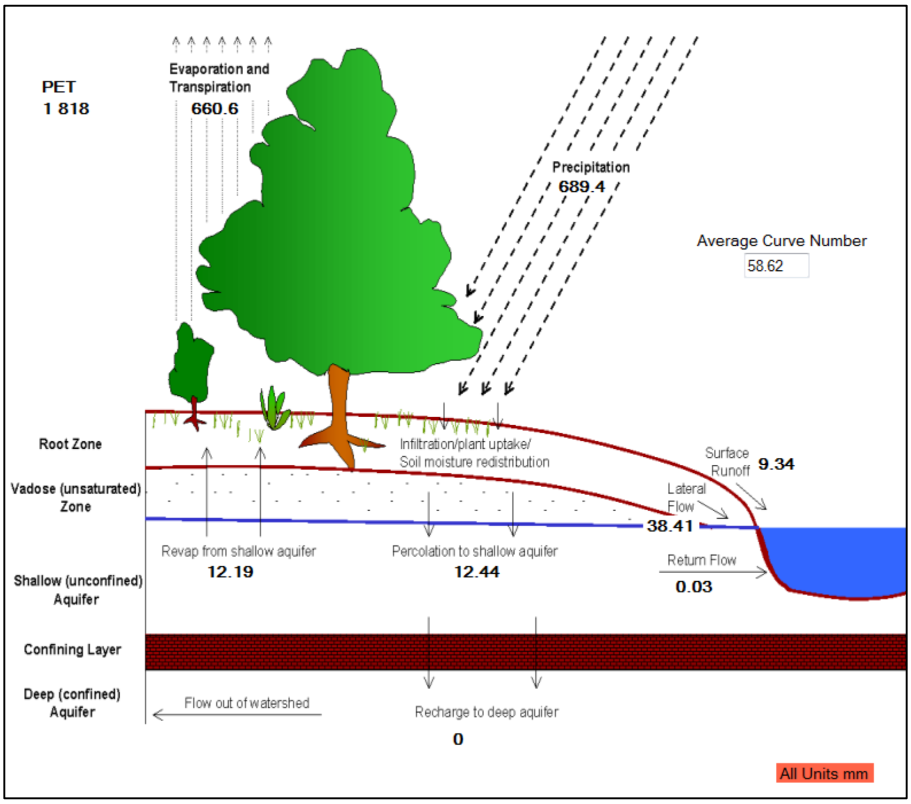
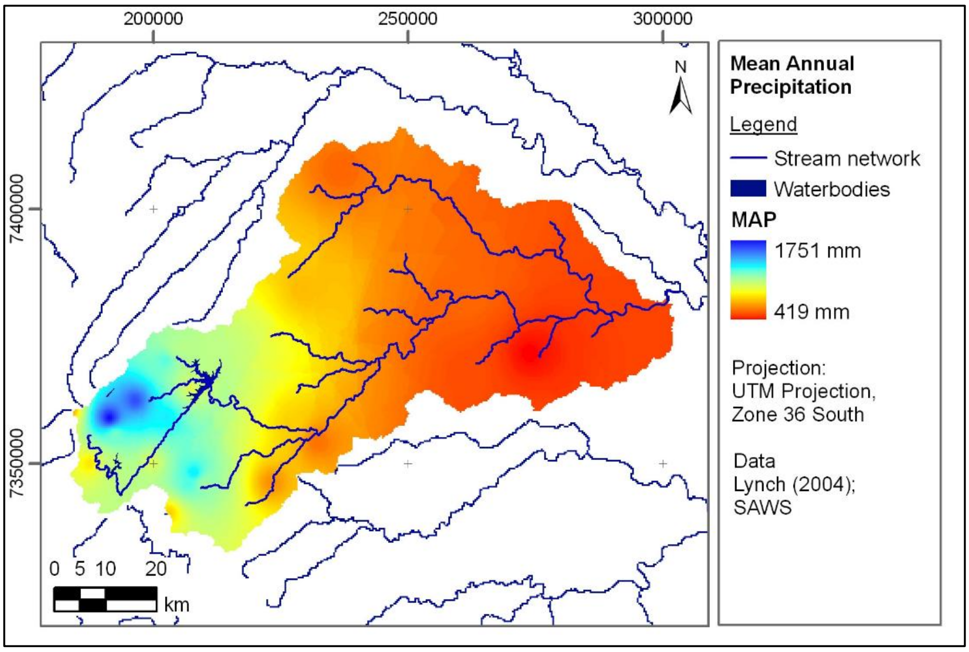


Figure 6.6 ArcSWAT scenario with 2050 climate data

It appears as though the precipitation data is contradicting. Upon inspection it should be noted that precipitation in not evenly spread throughout the region and that rainfall substantially diminishes as one moves east through the area (Scheffler, 2008). This correlates with the majority of agriculture and forestry activity being located in the western part or the catchment. The standard deviation of the rainfall per sub-basin is very high, which skews the average in favour of the few basins with very high precipitation levels.



(Scheffler, 2008)

Figure 6.7 Rainfall distribution throughout the Letaba catchment

On the whole, climate change is expected to impact traffic volumes in the scenarios in the following ways:

- Forestry is affected by both average temperatures, as well as precipitation levels. The expected change to forestry related freight volumes is the sum of the temperature and precipitation changes (7.5% growth);
- Agricultural traffic volumes (both passenger and freight) are modelled to grow by 21%, which is equal to the combined changes in crop and water yields as output by ArcSWAT in the 2050 simulation;
- Tourism is mainly affected by the change in precipitation levels and, hence, traffic volumes are reduced by 1.4% on all tourism related segments.

6.3 Environmental impact estimation methods

6.3.1 Air pollution

Carbon monoxide, hydrocarbon, nitrous oxides and sulphur oxides are emitted in a constant ratio with the transport activity per mode. To calculate the change in overall emissions for each of these pollutants, a weighted formula for the change in freight vehicle-kilometres and passenger vehicle-kilometres was used. Weights were based on the average difference in pollution emissions from different modes, published by Gilbert and Perl (2008).

It is recognised that actual travel speeds affect fuel consumption, thereby affecting the emissions of air pollution relative to driving speed, as well. The assessment in this study is, however, performed at a strategic level and such a detailed analysis falls beyond the scope of this study.

Particulate emissions are higher on gravel roads than on paved roads and this has to be accounted for in the low infrastructure development scenarios. To account for this, the portions of traffic on paved and gravel roads were determined and a weighted formula for the change in freight vehicle-kilometres and passenger vehicle-kilometres on each surface type was calculated. The total change in emissions from gravel roads was then multiplied by a factor of 1.5. This factor is the ratio between the speed limit on gravel and paved roads. It is expected that, because of a slower average travel speed on gravel roads, more pollutants will enter the air in the vicinity of the road.

Toxic metals are only emitted by some passenger vehicles and the total percentage change in these passenger vehicle-kilometres were used.

To calculate total air pollution, the individual percentage changes for each of the six pollutants included are added together. This amplifies the impact of air pollution, but is deemed realistic, as multiple pollutants are released, each with its own second and third order impact contributions.

6.3.2 Noise pollution

A weighted formula for the change in freight vehicle-kilometres and passenger vehicle-kilometres was used to calculate the change in noise pollution. Weights were determined based on the difference in decibels produced by freight (78db on average) and passenger vehicles (64 dB on average), respectively, as published on http://www.trolleycoalition.org/.

6.3.3 Biodiversity

Due to the difference in average travel speeds on gravel versus paved roads, it is expected that biodiversity will be impacted less when there are more gravel roads in a network. Traffic volumes and the density of infrastructure in an area are both directly proportional to the impact on biodiversity in that area. The sum of all three these changes between scenarios make up the total first order biodiversity impact.

Biodiversity is also affected by toxic metal emissions, noise pollution, erosion and water pollution as a second order impact. These first order impact changes are summed and added to the total biodiversity impact change value. The more second and third order impacts that a certain category receives, the higher its overall change will be, as many different factors contribute to the overall change effected.

6.3.4 Urban sprawl

It is assumed that an upgrade of a gravel road to a paved road will stimulate urban sprawl and, thus, the total increase in paved surfaces is used to represent the total change in urban sprawl.

6.3.5 Contamination

In order to calculate soil contamination, changes per sub-basin are calculated and summed for the entire area. ArcSWAT divided the catchment into 85 sub-basins, each with individual soil and hydrological properties (see Figure 6.9). The soils database used in the ArcSWAT model is derived from the land type database that resides with the Agricultural Research Council of South Africa. The soils in this database were physically and chemically characterised and this forms the most comprehensive soils database for South Africa. Figure 6.8 indicates the soil codes for the Letaba catchment. An example of the soil classification data (the physical characteristic of the soils) used within a land type unit in the model is given in Table 6.3.

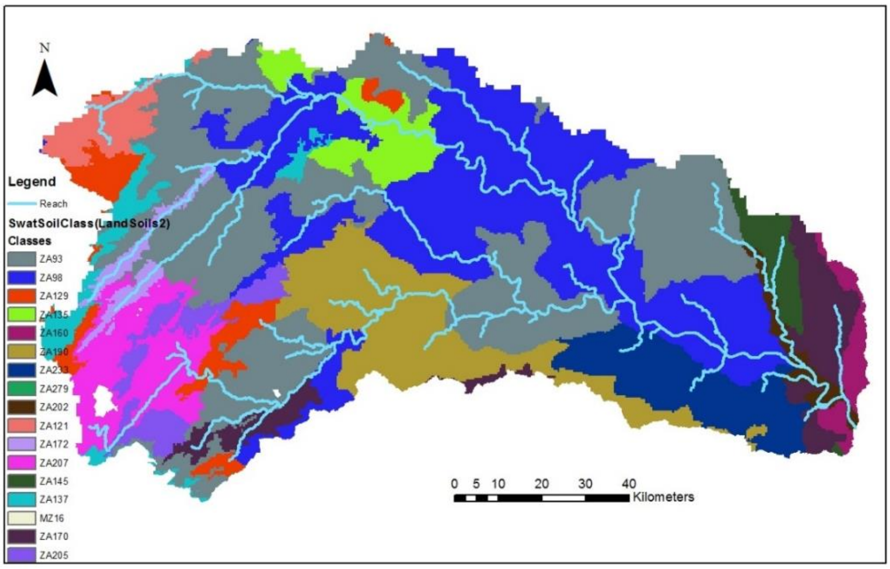


Figure 6.8 A soils map of the Letaba catchment createin in ArcSWAT

The road segments were mapped to the basins proportionally and from this mapping, the total change on all segments per sub-basin could be determined. Soil contamination is directly proportional to the volume of infrastructure within each sub-basin.

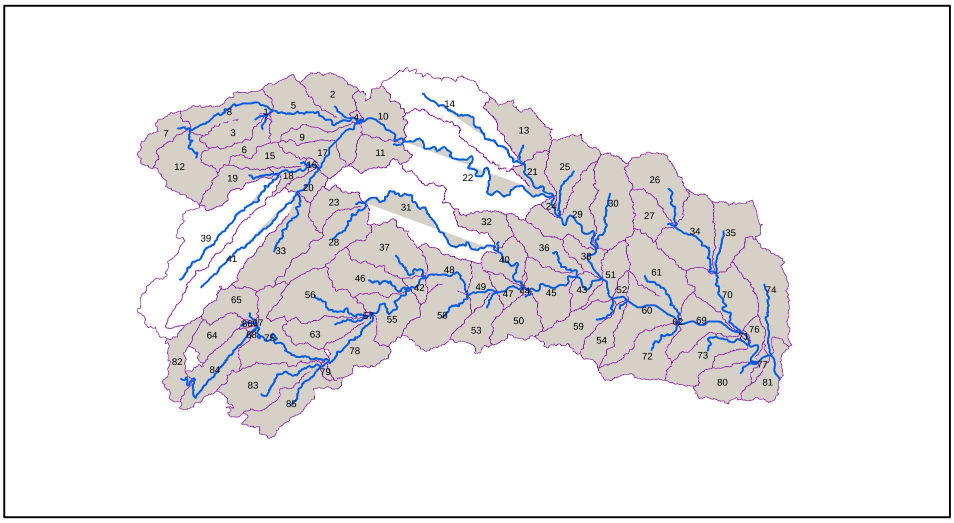


Figure 6.9 ArcSWAT sub-basin delineation

Table 6.3 An example of the land type soils classification data related to the SWAT modelling of the Letaba catchment

LAND TYPE / ***LANDTIP*** .... : **Db231**

CLIMATE ZONE *KLIMAATSONE* ...... : 1030S

Area / *Oppervlakte* .... : 38575 ha

Estimated area unavailable for agriculture
Beraamde oppervlakte onbeskikbaar vir landbou : 2000 ha

Occurrence (maps) and areas *Voorkoms (kaarte) en oppervlakte* :
2330 Tzaneen (38575 ha)

Inventory by *Inventaris deur* :
D G Paterson

Modal Profiles *Modale profiele* :
P1863

Terrain uni ***Terreineenhei***	1	3	4	5
% of land type *% van landtipe*	1	2	82	15
Area *Oppervlakte (ha)*	386	772	31631	5786
Slope / *Helling (%)*	2 - 8	5 - 40	1 - 6	1 - 6
Slope length *Hellingslengte (m)*	25 - 75	100 - 250	500 - 3000	100 - 300
Slope shape *Hellingsvorm*	Y	Y-X	Z	X
MB0, MB1 (ha)	39	77	30050	5208
MB2 - MB4 (ha)	347	694	1582	579

Soil series or land classes *Grondseries of landklasse*	**Depth** *Diepte* (mm)	MB	ha	%	ha	%	ha	%	ha	%	**Total** *Totaal* ha	%	**Clay content %** *Klei-inhoud %* A	E	B21	Hor	**Texture** *Tekstuur* Class / *Klas*	**Depth limiting material** *Diepte-beperkende materiaal*
Rock / Rots		4	154	40	386	50					540	1.4						
Arniston Va31, Lindley Va41, Glengazi Bo31, Bonheim Bo41	>1200	0					12652	40	1157	20	13810	35.8	20-30		35-45	B	me/coSaCl-Cl	
Balfour Es35, Swellengift Kd12, Slangkop Kd15	300-600	0					6326	20	579	10	6905	17.9	8-15	4-12	20-40	E	coSa-SaLm	pr,gc
Portsmouth Hu35, Shorrocks Hu36	400-1000	1	39	10	77	10	4745	15			4860	12.6	10-20		10-25	B	Lmme/coSa-SaClLm	R,so
Jozini Oa36, Koedoesvlei Oa37, Mutale Oa47, Shorrocks Hu36	1000-1200	0							2314	40	2314	6.0	20-30		25-40	B	me/coSaClLm-SaCl	R,so
Mispah Ms10, Shorrocks Hu36, Portsmouth Hu35	100-350	3	193	50	309	40	1582	5			2083	5.4	10-20		10-25	A	Lmme/coSa-SaClLm	R
Davel We32	400-600	1					1582	5	289	5	1871	4.9	10-20		20-35	B	coSaClLm	sp
Gelykvlakte Ar20, Waterval Va11, Craven Va21	>1200	0					1582	5	289	5	1871	4.9	35-55			A	me/coSaCl-Cl	
Sandveld Fw12, Kusasa Cf31	400-800	0					1582	5			1582	4.1	8-12	8-12		E	Lmme/coSa-SaLm	R,lc
Shorrocks Hu36, Makatini Hu37	400-1000	0					1582	5			1582	4.1	20-30		25-40	B	me/coSaLm-SaCl	R,so
Levubu Oa34, Venda Oa35, Jozini Oa36	1000-1200	0							579	10	579	1.5	10-20		10-30	B	Lmme/coSa-SaClLm	R,so
Stream beds/Stroombeddings		4							579	10	579	1.5						

6.3.6 Erosion

From the ArcSWAT model, data on the soil loss in each sub-basin can be obtained. This data is used to calculate a ratio between soil loss and the density of infrastructure (be it paved or gravel) in each sub-basin. This ratio is multiplied with the new infrastructure density values in each scenario and the difference between scenario I and the scenario in question is determined. Erosion is also affected as second order impact by water shortages, and so the total change in water shortages also needs to be added when determining total erosion change.

6.3.7 Water pollution

Water pollution, due to infrastructure change, is calculated in much the same way as soil erosion. Here, ArcSWAT outputs the sediment yield in each sub-basin. Pollutants often cling to sediment and the proliferation of pollution is seen to be directly equivalent to sediment volumes. Again, a ratio between sediment and infrastructure density is used to calculate the change in sediment between scenarios.

Water pollution, due to increased transportation volumes, is directly proportional to the traffic volume change per road segment, with the caveat that gravel roads contribute more (in relation to the speed differential between paved and gravel roads). Both volume and infrastructure induced changes need to be accounted for when estimating water pollution change.

On the second order impact level, water pollution is bolstered by nitrous oxide emissions, and the release of particulates during transportation. Erosion also exacerbates water pollution and the changes in all these elements are added to determine overall water pollution change.

6.3.8 Water shortages

As infrastructure disturbs the natural flow path of water, less water can penetrate the soil and supplement ground water stocks. ArcSWAT produces data on the volume of recharge entering aquifers in each sub-basin. A ratio between the volume of recharge and the volume of infrastructure is used to calculate the change in water availability. A difference between the impacts on water shortages from paved, as opposed to gravel roads, is accounted for as infrastructure changes between scenarios.

6.3.9 Road safety

The more particulates emitted, the higher the impact on road safety.

6.3.10 Health impacts

Health impacts are second order impacts only and is calculated as the combined impacts of air pollutants, noise pollution, biodiversity loss, erosion, water pollution and road safety.

6.3.11 Agricultural productivity

Soil contamination and erosion, along with water pollution and shortages and biodiversity loss all contribute to the second and third order impact of reduced agricultural productivity.

7. Transportation impact assessment results

7.1 No climate change simulation

The results for all scenarios under the no climate change assumption is shown in Table 7.1. The blue colour spectrum indicates positive impacts (dark blue is the most positive) and the red colour spectrum indicates negative impacts (dark red is the most negative). There are significant positive improvements in water shortages when gravel roads are upgraded to paved roads. The environmental impacts that can be considered compound impacts (i.e. they are contributed to by a multitude of factors) generally fare the worst. This is evident in the extremely high negative impacts on health, agricultural productivity loss, biodiversity loss and air pollution. Air pollution is a compound impact, despite being only a first order impact, as there are a number of individual air pollutants (such as CO and NO_x) that together constitute overall air pollution. When compound impacts are calculated, weights can be applied to distinguish between the relative importance of each subservient impact. Equal weights are used in this study, as we are interested in determining the extreme ranges of impact change.

The economic development of the agriculture sector results in higher levels of environmental impacts than that of tourism or mining sector development in the study region. This is attributable to the differences in scale of development and also to the large number of road segments affected by agriculture. Comparing pure infrastructure changes (scenario IV) to pure transport volume changes (scenario II), it is seen transport volumes have a greater effect on environmental impacts than infrastructure – economic development in the region will come at a hefty price in terms of the environment. When all infrastructure and volume changes are in play, there is a threefold increase in the impact on health in the region.

Table 7.1 Scenario result comparison table in the no climate change simulation

	Scenario I	Scenario II:A	Scenario II:B	Scenario II:C	Scenario II:D	Scenario III:A	Scenario III:B	Scenario III:C	Scenario III:D	Scenario IV
Air pollution	0%	42%	13%	16%	46%	47%	18%	22%	51%	6%
Noise pollution	0%	7%	2%	2%	8%	8%	3%	3%	8%	1%
Biodiversity loss	0%	48%	24%	29%	53%	92%	73%	78%	101%	56%
Urban sprawl	0%	0%	0%	0%	0%	2%	2%	2%	2%	2%
Soil contamination	0%	6%	4%	5%	7%	8%	5%	7%	9%	2%
Soil erosion	0%	0%	0%	0%	0%	24%	24%	24%	24%	24%
Water quality decline	0%	26%	12%	14%	28%	14%	0%	2%	16%	-7%
Water shortages	0%	0%	0%	0%	0%	-41%	-41%	-41%	-41%	-41%
Road safety	0%	8%	2%	2%	8%	8%	2%	3%	8%	1%
Health deterioration	0%	179%	77%	93%	196%	285%	194%	210%	309%	136%
Agricultural productivity loss	0%	80%	40%	48%	88%	97%	62%	71%	109%	34%

7.2 Climate change simulation

The climate change simulation results are summarised in Table 7.2. The general trend in these results mimic that of the no climate change scenario. Air pollution, biodiversity loss and agricultural productivity loss values are worse in this simulation where climate change is assumed to occur as expected by the CSIR (Engelbrecht, et al., 2011). This is mainly driven by the increased number of freight vehicles on the roads. Noise pollution, soil contamination and urban sprawl values remain largely the same, as none of these are really affected by climate change impacts. Soil erosion, however, is better in this simulation despite the same level of infrastructure upgrade. This is due to the improved soil loss values estimated in ArcSWAT based on a full hydrological analysis of each sub-basin. Water pollution somewhat deteriorates, due to the increase in agricultural freight volumes, but the reduction in soil loss more than offsets this increase when the infrastructure is upgraded. Health impacts in this simulation follow the same pattern as water pollution, highlighting the significance of water pollution's contribution to total health impacts. Summing over all changes in each simulation, a 15.5% reduction is seen in the total impacts in the climate change simulation (as opposed to the no climate change simulation). Thus, the local climate changes, resulting from expected global climate change, had a positive influence on total transportation impacts in the study area.

Table 7.2 Scenario result comparison table in the climate change simulation

	Scenario I	Scenario II:A	Scenario II:B	Scenario II:C	Scenario II:D	Scenario III:A	Scenario III:B	Scenario III:C	Scenario III:D	Scenario IV
Air pollution	0%	48%	13%	16%	52%	53%	18%	22%	57%	6%
Noise pollution	0%	8%	2%	2%	9%	9%	3%	3%	9%	1%
Biodiversity loss	0%	53%	24%	29%	57%	77%	53%	58%	86%	36%
Urban sprawl	0%	0%	0%	0%	0%	2%	2%	2%	2%	2%
Soil contamination	0%	6%	4%	5%	7%	8%	5%	7%	9%	2%
Soil erosion	0%	0%	0%	0%	0%	9%	9%	9%	9%	9%
Water quality decline	0%	29%	12%	14%	31%	12%	-4%	-2%	14%	-11%
Water shortages	0%	0%	0%	0%	0%	-40%	-40%	-40%	-40%	-40%
Road safety	0%	9%	2%	2%	10%	9%	2%	3%	9%	1%
Health deterioration	0%	199%	77%	93%	216%	245%	135%	151%	270%	77%
Agricultural productivity loss	0%	88%	40%	48%	96%	65%	24%	32%	78%	-4%

7.3 Uncertainty and sensitivity analysis

Despite authorities constantly planning for growth and development, nobody knows exactly what levels of development will actually be achieved. This uncertainty about the future can be addressed by modelling different potential futures, and learning from the differences between them. In this study, scenario modelling addresses uncertainty in terms of the level of economic development that will be realised within the region, the level of infrastructure provision that will be achieved and the changes in general climate of the region. Looking at the results, there is a spread between scenarios, but all the scenarios result in an increase in negative environmental impacts broadly in line with the scale of development in that scenario.

In terms of sensitivities, sub-scenarios A through C control for differences in the contributions from agriculture, tourism and mining expansion. Agriculture dominates the economic activity in the region and, as can be expected, also has the greatest influence on total environmental impacts. The contrast between scenario II and IV informs on the relative contribution of economic development impacts versus infrastructure development impacts.

7.4 Generalisation of results

The comparatively extreme values of compound impacts show that second order impacts, although often hidden from first sight, is extremely important and should never be disregarded from an impact assessment. The same goes for third order impacts. Furthermore, the environment pays the price for economic development and decision makers should be cognisant of these (probably unintended) consequences when planning for growth and expansion. Lastly, the upgrade from gravel roads to paved roads have large positive benefits in terms of water availability, which (especially in arid regions) can help to alleviate water pollution impacts and can reduce soil erosion and contamination. A major development goal should thus be to convert gravel roads to paved roads in water stressed areas. This should, however, be managed well, so that savings are not acquired by inducing increases in accidents, health impacts, noise and air pollution due to urban sprawl proliferation and higher average travel speeds. Also, a relative economic and environmental life-cycle cost comparison between paved and gravel roads needs to be taken into account.

8. Conclusions and recommendations

Most regional development initiatives will induce changes to the transportation system in the area. These changes could be to the volume of transport on the network, or to the network infrastructure, or both. Whilst the proposed developments might be beneficial economically or socially, they could unwittingly trigger a number of negative environmental impacts if this is not accounted for in the planning and management of said developments. An environmental impact assessment should not stop at the direct environmental impacts, but should also consider indirect and compound impacts. The Letaba district case study shows that these 'hidden' impacts are much more devastating than the 'obvious' impacts. Ignoring or omitting them gravely underestimates the true impact of a proposed development.

Climate change can affect the total impacts generated by a proposed development in three ways. Firstly, climate change will impact on transport volumes, predominantly because climate change influences the viability and extent of economic activities in a region and such economic activities are drivers of transportation. Secondly, climate change can render current infrastructure insufficient to deal with changed climatic conditions and increase the burden of infrastructure maintenance in a region. In poor areas this could lead to the rapid deterioration of infrastructure. Thirdly and finally, climate change can amplify the relationship between transportation and its environmental impacts. For example, changes in average precipitation affect the region's hydrological system to dilute and flush out pollutants. In this case, climate change could have a negative (reduced precipitation) or positive (increased precipitation) impact. Development plans normally span a long horizon; the amplification brought about by climate change needs to be borne in mind in these cases.

Transport, the environment, climate change, a region's hydrology, its agricultural productivity and food security all form an interrelated system that needs to be balanced to achieve true sustainability.

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Appendices/

Transport impact assessment road configuration/

Road segment name	Alternative road codes	Segment start identifier	Segment end identifier	Shopping changed volumes (passenger)	Agricultural changed volumes (freight)	Agricultural changed volumes (passenger)	Forestry changed volumes (freight)	Mining volume change (freight)	Tourist volume change (passenger)	Paved roads upgraded to good	Gravel roads upgraded to paved	Giyani airport induced traffic (passenger)	Taxi rank upgrade induced volumes (passenger)	Bus rank upgrade induced volumes (passenger)
R36a	D1308	Morebeng	Mooketsi											
R36b/R81b	P43/2 D1308 overlap	R81	R36											
R36c	P43/2	Mooketsi	Modjadjiskloof											
R36d	P17/3	Burgersdorp	D4157											
R36e	P17/3	D4157	Tzaneen											
R36f	-	Modjadjiskloof	R71											
R71a	-	Moria	Haenertsburg											
R71b	R17/2	Haenertsburg	D668											
R71c	R17/2	D668	R36											
R71d	P17/3; P43/3	R36	Mashutti turnoff											
R71e	P43/3	Mashutti turnoff	D2283											
R71f	P43/3	D2283	R529											
R71g	P43/3	R529	P43/3											
R71h	P112/2	P43/3	Rubbervale											
R81a	P43/2; R526	Munnik	R36											
R81c	D9	R81	D3238											
R81d	D9	D3238	D3815											
R81e	D9	D3815	D3634											
R81f	D9	D3634	D3805											
R81g	D9	D3805	Ka-Mphambo											
R529a	D1267	Giyani	Sikhunyane											
R529b	D1267	Sikhunyane	R71											
R592c	D8	Letsitele	Mafarana											
R578a	P99/1	R81	D3238											
R578b	P99/1	D3238	D3832											
R578c	P99/1	D3832	D3754											
R578d	P99/1	D3754	D3748											
R578e	P99/1	D3748	D3727											
R578f	P99/1	D3727	D3830											
R578g	P99/1	D3830	D4											
D3641a	-	D3815	D3641											
D3641b	-	D3641	D3809											
D3641c	-	D3809	D3802											
D3641d	-	D3802	D3800											
D3641e	-	D3800	Gravel											
D3641f	-	Gravel	D3799											
D3810d	D3980; D3981	D3187	P43/3											
D3634a	-	R81	D3816											
D3634b	-	D3816	D3778											
D3778	-	D3634	D3753											
D3753	-	P99/1	D3750											
D3187c	-	D1267	D3981											
D3766	-	P17/3	D8											
D8	-	D3766	R71											
D4139	-	D3889	D3880											
D3880a	-	D4139	D3873											
D3880b	-	D3873	D3762											
D3880c	-	D3762	P17/3											
D548a	D528	D1286	R36											
D548b	-	D1286	Haenertsburg											
D5011a	-	D3763	D673											
D5011b	-	D3763	D8											
D673a	-	D673	P17/3											
D673b	-	P17/3	R71											
D1292a	-	R71	D3247											
D1292b	-	D3247	D1267											
D3848	-	D2512	D3187											
D978a	Mashutti road	R71	D447											
D978b	-	D447	D1714											
D978c	-	D1714	D1350											
D1350a	-	D1292	D987											
D1350b	-	D987	D1326											
D1350c	-	D1326	D1326											
D1350d	-	D1326	D1350											
D3185	-	D9	D3641											
D3247	-	D3248	D1292											
D3202	-	D3187	D1267											
D3766	-	R36	D8											
D11	-	R81	D3150											
D3150	-	D11	Mamaila											
D3840a	-	R81	D3836											
D3840b	-	D3836	D3837											
D3840c	-	D3837	Nkomo											
HomoS-B	-	Giyani	Homo											
D3182	-	Homo	Mapayeni											
D3810a	-	D3641	D3801											
D3810b	-	D3801	D3840											
D3810c	D3980	D3840	D3187											
D3810e	D3260	P43/3	D1191											
D3799	-	D3641	Muyexe											
D3187a	-	D3200	D3221											
D3187b	-	D3221	Paved section											
D3843	-	Mageva	D1267											
D3180a	-	D447	D3184											
D3180b	-	D3184	D3198											
D3180c	-	D3198	D3213											
D3180d	-	D3213	D3220											
D3180e	-	D3220	D3211											
D3180f	-	D3211	Gravel section											
D3180g	-	Gravel section	D1267											
D3837	-	D1267	D3840											
D3873	-	Gravel	D3880											

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