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Sustainable Rural Development in View of Water Resource management in Zambia

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In Prague ....

Declaration

I declare that the presented bachelor´s thesis entitled "Sustainable Rural Development in View of Water Resource management in Zambia" was prepared separately with use of the referred literature. I agree with the storage of this work in the library of CULS in Prague and making it available for further study purposes.

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Acknowledgements

I would like to express my appreciation everyone who helped me at work on this thesis. Special gratitude belongs to my supervisor Prof. Ing. Bohumil Havrland, CSc. for his assistance, guidance and consultations which has been very helpful. Thanks belong also to Doc. Ing. Jakub Štibinger, who has helped me in matters of water management.

ABSTRAKT

Hlavním cílem této práce je studie zabývající se stavem Zambijského zemědělství a to především v oblasti vodního hospodářství a zavlažování. Analyzuje dopad klimatických změn na Zambijské hospodářství. Práce se následovně snaží navrhnout řešení pro zlepšení úrovně zavlažování v období sucha za pomocí metody obnovování podzemních vod. Zvláštní pozornost je věnovaná metodám obnovování podzemních vod v Indii.

Metodologie práce byla následující. V první části práce, v literární rešerši je analyzován stav Zambijské společnosti, zemědělství a vodního hospodářství. Je zde také analyzován dopad klimatických změn na hospodářství Zambie a seznámení se s problematikou obnovování podzemních vod. Druhá část práce se zabývá matematickou analýzou, ve které jsou kalkulovány závlahové potřeby rostlin typické pro Zambijské zemědělství, a výpočtem potenciálního množství vody pro účely závlah obnovené za pomocí metod obnovování podzemních vod. Následně jsou porovnány výsledky, které jsou zanalyzovány, a podle nich je vypracováno doporučení pro budoucí výzkum v oblasti vodního hospodářství Zambie.

Výsledky práce ukazují, že metody obnovování podzemních vod mají potenciální přínos pro Zambijské zemědělství. Obnovování podzemních vod za pomocí specifických staveb dokáže zajistit potřebnou závlahovou vodu pro plodiny pěstované v Zambii. Práce také prokazuje, že zemědělství Zambie je závislé na míře srážek. Dále jsou zde prezentovány odhady obnovy podzemní vody určitou stavbou a její schopnost zavlažovat určitou plochu dané pěstované plodiny.

Hlavním přínosem této práce je analýza zemědělství Zambie v oblasti zavlažování a zhodnocení možné aplikace metod obnovování podzemní vod v Zambijském prostředí.

Klíčová slova: Zambie, vodní hospodářství, podzemní voda, obnovování, Zavlažování

ABSTRACT

The main objective of this work is the study of the condition of Zambia agriculture, especially in the field of water management and irrigation. It analyzes the impact of climate change on the Zambian economy. The work subsequently seeks to propose solutions for the improvement of irrigation during the dry season using the methods of artificial recharge of groundwater. Particular attention is devoted to methods of artificial recharge of groundwater in India.

The methodology was as follows. In the first part, the literature review analyzes the state of the Zambian society, agriculture and water management. It also analyze the impact of climate change on the economy of Zambia and familiarization with the issue of methods of artificial recharge of groundwater. The second part deals with the mathematical analysis, in which are calculated the irrigation needs of plants typical for Zambian agriculture and the calculation of the potential amount of water for irrigation purposes restored using the methods of artificial recharge of groundwater. Then the results are compared and analyzed. According to them, recommendations are prepared for future research in the field of water management in Zambia.

The results show that the methods of restoring groundwater have potential benefits for Zambian agriculture. Restoring groundwater using specific structures can provide the necessary irrigation water for crops in Zambia. This work also shows that the agricultural of Zambia is dependent on the rate of precipitation. There are also presented estimates of recovery groundwater by particular structure and its ability irrigate particular area of the cultivated crops.

The main contribution of this work is the analysis of agriculture in the field of Zambian irrigation and possible application of artificial groundwater recharge in the Zambian environment.

Key words: Zambia, Water management, Ground water, recharge, Irrigation

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List of Abbreviations

- MCM - million cubic meters
- Lps – liters per second
- GDP – gross domestic product
- UN – United Nations
- HDI – Human Development Index
- IMF - International Monetary Fund
- FAO - Food and Agriculture Organization
- IPCC – Intergovernmental Panel on Climate change
- NCAR - The National Center for Atmospheric Research
- CSIRO - Commonwealth Scientific and Industrial Research Organization
- IRW – Internal renewable water
- ISWR – Irrigation water supply reliability

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1 Introduction

“What makes the desert beautiful,' said the little prince 'is that somewhere it hides a well...”

— Antoine de Saint-Exupéry, The Little Prince

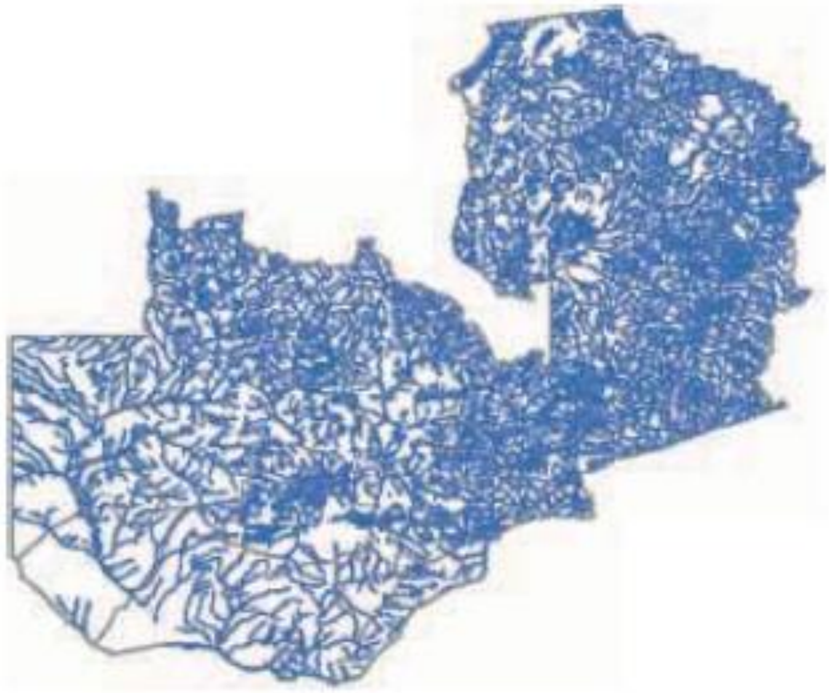
Zambia is a county in Southern part of Africa, which is named after river Zambezi flowing in its territory. It is landlocked country, which has borders with Angola, Democratic Republic of the Congo, Tanzania, Malawi, Mozambique, Botswana and Namibia. Zambia takes area of 752, 612 sq km and its climate is tropical. The country consists of a high plateau which lies mostly between 900 and 1 500 m of elevation. Capital of Zambia is Lusaka. Population is estimated on 13,460 000 (Siamusantu S et al., 2009).

Zambia is the country with high agricultural potential. Due to the good climate and abundance of fertile land it is possible to grow different amounts of crops and breeding livestock. But it is not sufficiently used. Due to weak technological level in agriculture, Zambia has poor food security, which causes malnutrition of significantly large part of the population (Siamusantu S et al., 2009). One of the main problems affecting the food security of the alternating two seasons - rainy season and dry season. It often occur floods or droughts, which have a striking impact on the production of strategic crops (Nyambe and Feilberg, not dated). This phenomenon could be even more crucial if occurs climate models, which analyze actual climate changes (Wit M, 2006).

Zambia is a country with great potential for water management. In this area there is a large quantity of water resources (Figure 1), whether it is groundwater or surface. A large amount of this water is not used for irrigation during the dry season, which would cause enough moisture for plant growth (Nyambe and Feilberg, not dated). Another problem is the non-use of rainwater during the rainy season (Yakima L, 2011). And just this problem could be solved by applying the methods restoring groundwater, which is used in India. These are methods whose main objective is to capture water and subsequent storage in underground storage capacities. Under appropriate conditions, there may be stored and subsequently used for irrigation. Restoring groundwater could thus help to overcome the unpleasant consequences of drought. Helping with establish a renewable Zambian agriculture development and the stabilization of food security.

Head idea of this bachelor work is provide enough information about Zambia food crisis problem and its possible solution by improvement of water resource management. It describes Zambia conditions in view of the climate, agriculture and irrigation management. The author of this work tries sum up the causes of irrigation issues that affect food production and find solution of these issues in artificial groundwater recharge and rainwater harvesting. These sustainable methods are commonly used in countries like India, where is the problem with lack of water supply. Nowadays, when the drastic climatic changes influence agriculture in many countries, the issue of water management is hot topic.

Figure 1.: Zambia surface water resources



Source: Nyambe and Feilberg, not dated

2 Reference Analysis and Theoretical Considerations

2.1 Zambia General Information

Zambia is landlocked country in Africa. It is located in south-central part of Africa. The name takes from river called Zambezi. It border with eight countries, which are Democratic Republic of the Congo, Tanzania, Angola, Namibia, Botswana, Zimbabwe, Mozambique and Malawi. It takes area of 752, 612 sq km. The country consists of a high plateau which lies mostly between 900 and 1 500 m of elevation (Siamusantu S et al., 2009). Population is estimated on 13,460 000. With density about 46.3 persons per sq km, Zambia's population is small relative to the area. The capital of Zambia is situated in the south-central part of the country. It's called Lusaka and it is on a limestone plateau 1, 280 meters above sea level. Population of the city is estimated on 1,084,703.

The form of government is multiparty republic with one legislative house. Head of state and government is President (Encyclopaedia Britannica, 2012). The Zambia's ranking in Democracy index from report of the Economist Intelligence Unit is in state of Authoritarian regime; rank 71 (For comparison Czech Republic is in state of Full democracy; rank 16) (Economist Intelligence unit, 2011). Transparency International evaluates Zambia with Corruption Perceptions Index 37 and it is eighty-eighth most corrupt country in the World (For comparison Czech Republic rating is 49 and it is fifty-fourth most corrupt country in the World)(Transparency International, 2012).

Zambia gross domestic product (GDP) per capita in year 2011 reached 1,425 USD. Gross National Income reached 1,160 USD (World Bank, 2013). In this year Zambia’s economic growth slowed to 6.6 % from 7.6% in 2010 (Table 1). It is mainly result of a weaker mining sector performance. The agriculture accounts 21 % of the local economy. But it is vulnerable to weather conditions and it is highly dependent on rainfall. To deal with infrastructure lacks, the Zambia Government has increased the agriculture budget allocation in 2012 by 6.1%. The part of this allocation is assigned to Farmer input Support Programme and for funding the strategic food reserve. There also another key areas of development. Like development of Irrigation infrastructure, livestock, fisheries and aquaculture development (African Economic Outlook, 2012). According to Human Development Index (HDI), Zambia is in status of Low Human Development country. It takes 163th position out of 186 countries. This fact is caused by several reasons. For example, 64.2 % of Zambia population lives in poverty (UNDP, 2013). But there are large differences between rural and urban areas. One of the reasons of this high level of poverty is due to poor work opportunities for young people. This statement is confirmed by the values. In urban areas, 63 % of the 15-19 age group is unemployed. And in the 20-24 age group, it is improved 48 %. Opposite it, 16% of the 15-19 age group and 7% of the 20-24 age group are unemployed in countryside. Zambia, as country with no access to a sea, has economic policy goals that include continued development trough Southern African Development Community and the Common Market for Eastern and Southern Africa and Southern Africa. As a member of Commonwealth, Zambia also have traditional ties with other Commonwealth members. It is also member of the United Nations (UN) and a member of the African Union. Zambia is supported in development assistance from a number of countries, the World Bank, and the IMF (Encyclopaedia Britannica, 2012).

Table 1.: Macroeconomic Indicators

	2010	2011	2012	2013
Real GDP growth	7.6	6.6	6.9	7.3
Real GDP per capita growth	4.8	3.7	3.9	4.2
CPI inflation	8.5	8.7	8	8.5
Budget balance % GDP	-3	-2.6	-3.6	-3
Current account % GDP	3.6	5.4	3.6	4

Source: African Economic Outlook, 2012

Table 1. shows the changing macroeconomic values from 2010 to 2013.

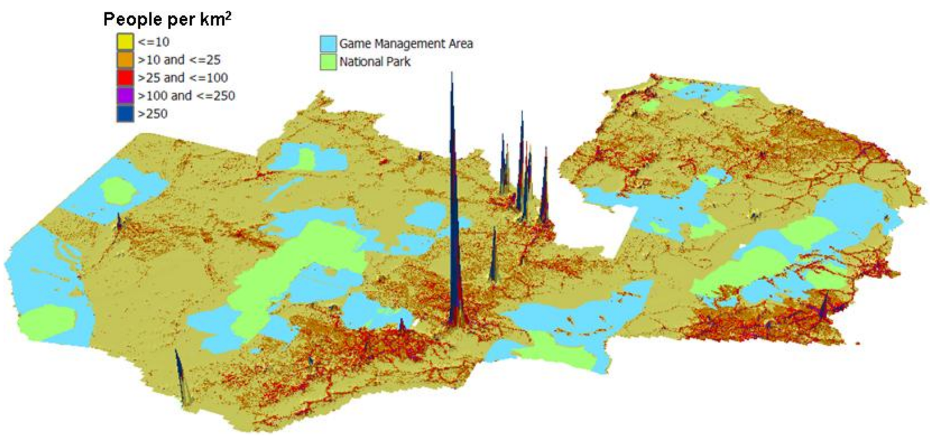
According to Encyclopædia Britannica, most Zambians are of Bantu origin. The complicated progress of immigration has produced many linguistic and cultural varieties. The Bemba ethnicity is the most widespread group. It accounts for more than one-fifth of the population. Bemba group is placed in the north-central part of the country. This means in the Northern, Luapula, and Copperbelt provinces. The two next groups, called Nyanja (also known as Chewa) and Tonga, are also important and each account for more than one-tenth of the population. Nyanja language is spoken in the Eastern and Central provinces, while Tonga languages is spoken mainly in the Southern and Western provinces.

In Zambia, there are seven official dialects: Bemba, Nyanja, Lozi, Tonga, Luvale, Lunda, and Kaonde. English is the official and administrative language of government and is used for education, commerce, and law.

Zambia is predominantly a Christian country. The first Christian missions came before colonial times and they established schools, which helped to the growth of believers. Today, the largest church in Zambia is The Roman Catholic Church, but Protestants churches are also established. There is also growth of fundamentalist churches since independence, and nowadays the government of the Zambia is in conflict with two of these churches, the Jehovah's Witnesses and the Lumpa church. The Hindu is head religion of The Asian community. But minority of Asians follows Muslims faith. There is small number of Muslims among the African population (Encyclopaedia Britannica, 2012).

The most of the population is concentrated along the *Line of Rail* and also Copperbelt provinces, where main industrial areas are (map 1) (Sitko at al., 2011). Life within towns and cities is very variable and has become increasingly separated along class levels. There is a trend of migration toward urban centers in Zambia; In the Zambia's rural areas have occurred important changes. Many of the migrants are male. Women usually remain behind in households, where they manage it and take care of their families. Most rural Zambians live from agricultural activities such as farming or herding and may participate in craftwork on a seasonal basis to supplement their sustenance. For some farmers, it is the only way to get cash (Encyclopaedia Britannica, 2012). There is also a comparison of direction of migration, which has been measured between 1998 and 2004. It shows that in Zambia there are more rural to rural and urban to urban migrants than rural to urban and urban to rural migrants (Siamusantu S et al., 2009).

Figure 2.: Population Distribution in Zambia



Source: Sitko at al., 2011

The marked population growth and urbanization creating new demands on health care, food, sanitation and education system. According to census in 2000, grow of population in Zambia was determined from 9,885,951 in 2000 to 13,273,571 in 2010 (Figure 2). Majority of population resides in rural areas. It is about 64 % of population (Security research project, 2011). An in total number, it is 8,197,437 (World Bank, 2013). 36 % of the total population was estimated to live in urban areas in 2005. As a result of the production and export of copper, Zambia achieved high levels of rural to urban migration during the 1960s and 1970s. Lusaka is still the head destination for people from countryside. It is followed by the Copperbelt province. The proportion of urban population has decreased, from 40% of total population in 1980 to 38% in 1990 and 36% in 2000. It is caused by the decline in economy. The estimate in year 2005 shows that this reduction of urban population has stopped. Life expectancy at birth has decreased during twenty years. From 52 years in 1980-85 to 39 years in 2000-2005 (Table 2). This phenomenon is mainly caused by the HIV/AIDS pandemic (Siamusantu S et al., 2009).

Table 2.: Population indicators

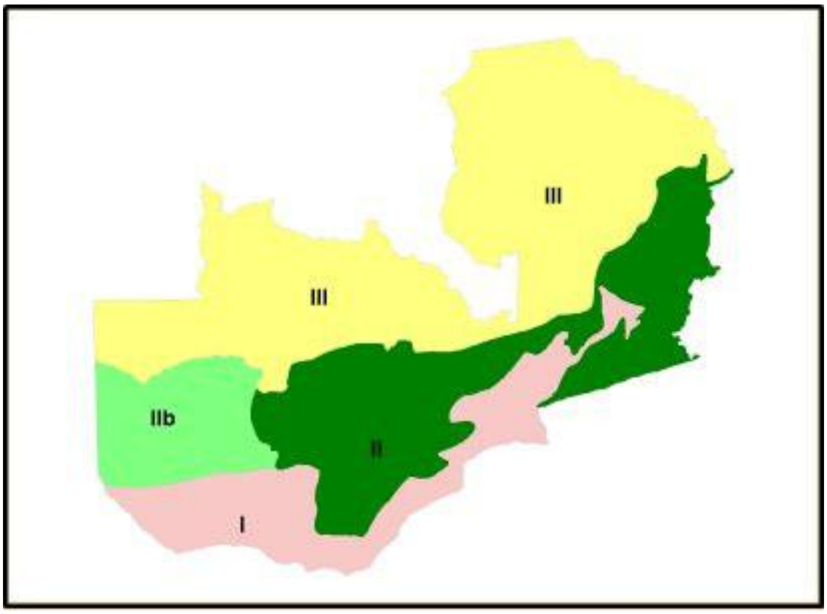
Indicator	Estimate	Unit	Period	Source
Total population	11.478	million	2005	UNPD
Annual population growth rate	1.88	%	2000-2005	UNPD
Crude birth rate	41.9	‰	2000-2005	UNPD
Population distribution by age:			2005	UNPD
0-4 years	17	%		
5-14 years	28	%		
15-24 years	21	%		
60 and over	5	%		
Rural population	64	%	2005	UNPD
Agricultural population	67	%	2004	FAO
Population density	15	inhabitants per km2	2005	UNPD
Median age	17	years	2005	UNPD
Life expectancy at birth	39	years	2000-2005	UNPD
Population sex ratio	99.1	males per 100 female	2005	UNPD
Net migration rate	-1.5	‰	2000-2005	UNPD
Total dependency rate	95	%	2005	UNPD

Source: Siamusantu S et al., 2009

According to Nutrition country profile document, the Zambia is separated into three agro-ecological zones. These zones are divided on the basis of rainfall pattern and soil type:

- Agro-ecological zone I (Figure 3), which contains areas of valleys situated in southern and western parts of the country. In these areas, annual rainfall is less than 800 mm and it is considered like a generally dry area. Best utilization for this area is in livestock rearing and production of small grains. In this region, crop production is mostly for household survival. Many locals depend on allocation of food from other parts of Zambia.
- Agro-ecological zone II (Figure 3), which is located in the central part of Zambia and has annual rainfall in range of 800 mm to 1 000 mm. It is separated into two sub-zones. First includes the most productive areas in the Zambia, which are the plateau areas of Lusaka, Southern and Eastern and Central provinces. Second sub-zone is less productive and covers the Kalahari sand plateau and Zambezi flood plains. This area is suitable for growing Cassava and Rice. And also for cattle breeding.
- Agro-ecological zone III (Figure 3) is an area with high annual rainfall, which amounts exceeding 1000 mm per year. It covers Northern, North-Western, Luapala, Copperbelt and some northern parts of Central province. In this region, soils used to be highly acidic, which results in limitation of production potential (Siamusantu S et al., 2009).

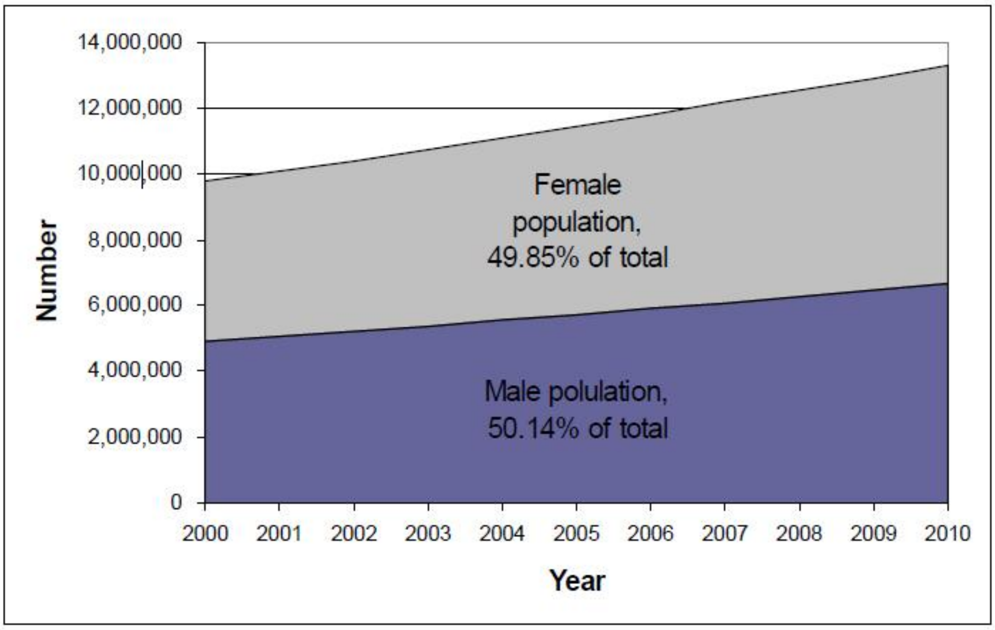
Figure 3.: Agro-ecological zones of Zambia



Source: Climate Wit M, 2006

The majority of Zambia's labor force is employed in Agricultural. Zambia is country with huge land area and many natural resources. However, only about 1/6 of the country's arable land is under utilization (Encyclopaedia Britannica, 2012). In fact, from arable land only 31.5 % is Agricultural land (World Bank, 2013). Farms range values are in size from household farms to large commercial farms. Smallholder farmers use mainly hand-tool technology, and their mainly production is food crops such as maize, sorghum, millet, cassava (manioc), and groundnuts (peanuts) (Encyclopaedia Britannica, 2012). The smallholder sector counts about 430 000 farming households which cultivate about 1–2 ha for own consumption and occasional for market (Siamusantu S et al., 2009). Medium and large commercial farms use improved seed and fertilization technologies, and animal draft power for heavy operations (Encyclopaedia Britannica, 2012). Their quantity is estimated 250 000 farms (Siamusantu S et al., 2009). The country's large commercial farms are mainly situated along the Line of Rail and are mostly owned and operated by white Africans. This state has roots in colonial history of Zambia when native males were recruited to work the mines while European settlers worked in agriculture sector. The settlers were given fertile land along the Line of Rail while natives were relocated to farm on lesser quality land. This situation has changed to some degree because of land reform programs (Encyclopaedia Britannica, 2012).

Figure 4.: Population Projections, 2000-2010



Source: Sitko at al., 2011

Cattle breeding can be found in the drier regions of the country with open woodland vegetation. These regions are mostly tsetse-free. Breeding zones are mainly at the Tonga plateau, the Kafue Flats, and the floodplain of the upper Zambezi (Encyclopaedia Britannica, 2012). According to report of Ministry of agriculture and co-operatives in 2003, the Zambian livestock population in line with species is marked in table 3 (Ministry of Agriculture and Co-operatives, 2003).

Table 3.: Livestock population

Species	Population
Cattle	2,846,000
Goats	1,150,000
Pigs	480,080
Sheep	80,499
Donkeys	965
Commercial broilers and layers	20,000,000

Source: Ministry of Agriculture and Co-operatives, 2003

About 35 % of Zambian agricultural GDP are produced by the livestock sector. Cattle breeding, goats farming, pigs farming, sheep farming and poultry farming provide various food products. It is also very noticeable income for rural population. Some species of livestock population can be used for draught power.

In Zambia, there are three types of workers engaged in livestock sector. These farmers are primarily divided by quality of agriculture techniques used at livestock care.

In the first sector are mainly traditional farmers. Most of them are found in countryside. These herdsmen haven´t got any official document of ownership for the land and therefore they use communal pastures. It is not specified, how many heads of livestock these farmers own. It can be from few to several hundreds. These people don’t use some additional feed and their approach to control of diseases and parasites is poor. They also lack basic equipment and facilities. Crossbreeding is arranged by natural service, not by artificial insemenation. In this category, farmers keep mainly local breeds (Table 4), but there may be found some crosses between exotic and indigenous breeds.

Medium-scale farmers are classified to the second sector. These farmers are on higher level of formal education and mostly they are holders of official ownership document to the land.

Compared to traditional farmers, medium-scale farmers have some facilities for livestock. Their livestock feed by grazing on pastures, but farmers also provide additional feed for it. These farms have improved management and livestock is controlled against parasites and diseases. Crossbreeding is more variable and covers natural service and artificial insemination. Farmers keep crossbred, indigenous stock and also few exotic breeds.

In the third category are Commercial farmers. This group includes most provided farmers. They have specific facilities and objectives for their livestock and also improved access to road network, because their farms are mainly located along the line of rail. This is also associated with a high level of management on the farms (Ministry of Agriculture and Co-operatives, 2003). These farms also provide employment for many people (Aregheore M et al., 2009). Crossing, nutrition and veterinary activities in the hands of commercial farmers are of high standard. Livestock population reaches up to several thousand head of cattle (Ministry of Agriculture and Co-operatives, 2003).

Table 4.: indigenous cattle

Indigenous cattle	**Indigenous cattle (%)**
Angoni	22%
Barotse	25%
Tonga Cattle	52%
Baila	1 %

Source: Aregheore et al., 2009

2.2 Zambian irrigation and water resource development

Zambian agriculture is increasingly dependent on irrigation (Recent Changes in Small-scale Irrigation in Zambia, 2009). The beginnings of irrigation systems dawned in 1970 at Nakambala, on the south side of the Kafue Flats. In this region, Zambia Sugar Company has large ground (more than 101,000 hectares) under growing sugarcane. Their refinery is important for exports sugar and also for smallholders and their cane-growing projects. There is also another irrigation scheme at Mpongwe, near Luanshya. It produces wheat and coffee. Two coffee Arabica schemes are in Kasama. And there is also irrigation scheme for wheat and cotton in the Gwembe, using water from Lake Kariba (Encyclopaedia Britannica, 2012).

To achieve food security and poverty alleviation, Zambian government proposes increase the utilization of water resources for development of irrigation schemes. Development of irrigation is considered as the most suitable solution for reduction of food insecurity caused by dependence of agriculture on rainfall.

Policies of government rely on the information that in Zambia are significant water resources, which are not used. After all, Zambia is most water-rich country in the Southern Africa. Renewable water resources located in the territory of Zambia were set at 80 cubic km, although all water consumption in 1994 amounted to 1.7 cubic kilometers. 77% of consumption was consumed by agriculture and it was used primarily for irrigation. According to some estimates, less than 40, 000 ha of land was under irrigation for the period 2002-2004. Mostly this land was irrigated by commercial farmers. The water rights survey (1994) estimated land under irrigation at 53,000 ha (Table 5 and 6). Only 210 ha from this estimate were managed by smallholders. However these data do not include information about traditional irrigation of small farmers. 100,000 hectares of land was under traditional irrigation in 1992, according to the FAO (Kodamaya, 2009).

Table 5.: Distribution of irrigated area by provinces according to this table

Province	**Irrigated area (ha)**
Central	5295
Copperbelt	14610
Luapula	584
Lusaka	11583
Northern	652
Southern	13676
Zambia	**46400**

Source: Siebert et al., 2002

As it can be seen from the above, agricultural performance of Zambia is very vulnerable to unstable precipitation. Very poor irrigation system contributes to these conditions as well as lack of employees in agricultural extension systems too (Siamusantu S et al., 2009).

Table 6.: Land use and Irrigation

Type of are	Estimate	Unit	Reference period	Source
Total land area	74 339	1000 ha	2003	FAO
Agricultural area	48	%	2003	FAO
Arable lands & permanent crops	7	%	2003	FAO
Permanent crops	<1	%	2003	FAO
Permanent meadows and pasture	40	%	2003	FAO
Forested land areas	57	%	2005	UNSTAT
Irrigated agricultural land	<1	%	2003	FAO
Arable & permanent cropland in Ha per agricultural inhabitant	0.72	ha per agricultural Inhabitant	2003	FAO

Source: Siamusantu S et al., 2009

2.3 Climate Changes in Zambia

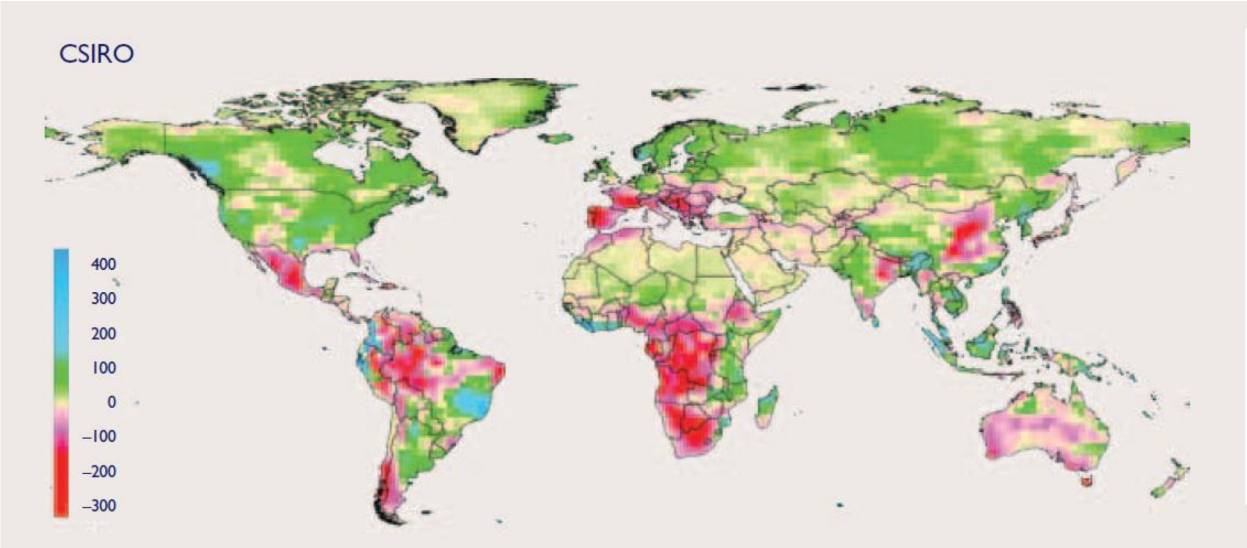
According to Intergovernmental Panel on Climate Change (IPCC), the climatic changes in atmosphere are real and in progress. These changes will have an impact on agriculture worldwide and it encumbers mainly developing countries, which cannot meet the goals of the Millennium Development Goals. It will also prevent reduce poverty and establish safeguard food security.

Rising population has resulted in increasing demands in the agricultural sector, which burdens the water and soil resources. Emerging greenhouse effect in the atmosphere greatly influences the climate worldwide and agro-ecological and growing conditions. This fact can be a significant obstacle to continued economic development in developing countries.

One of the main potential effects that may occur is seasonal changes in annual rainfall and Evapotranspiration (Wit M, 2006). Climate change will also have different effects on irrigated yields across regions (Figure 5 and 6) (Nelson et al., 2009). The intensity, frequency, duration and amounts of precipitation are most probably influenced by climate change. Precipitation changes are associated with radiation forcing, which changes due to the greenhouse effect in the atmosphere. This causes heating of the surface. The actual values of heating depend on certain feedbacks, such as water vapor feedback, ice-albedo feedback, and effects of changes in clouds.

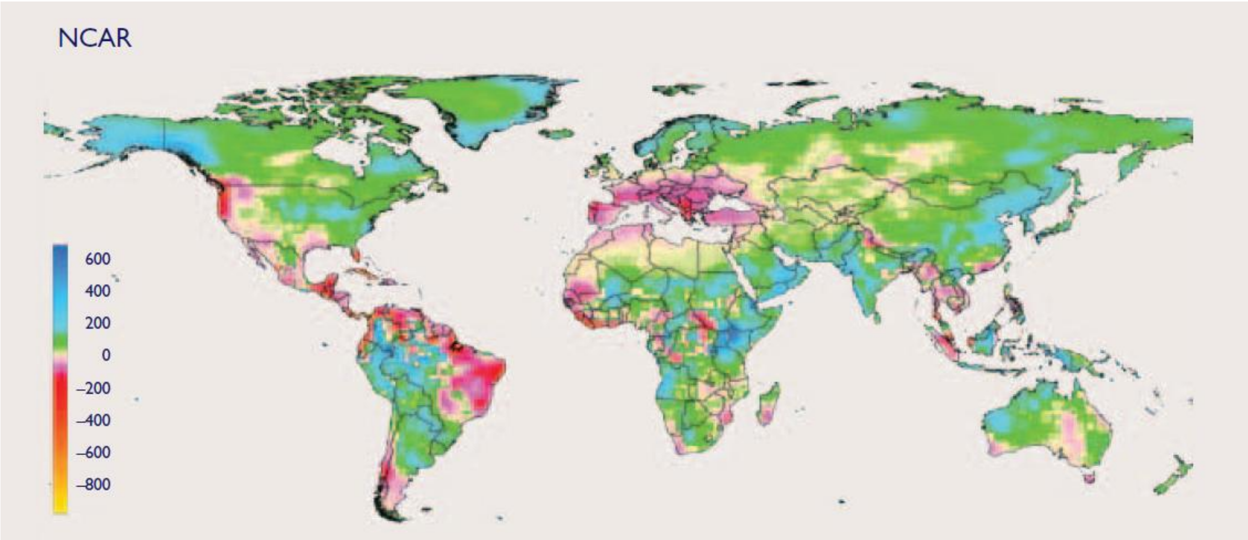
All of this is an important fact for climate models that determine the characteristics of precipitation (Trenberth et al., 2003).

Figure 5.: Change in precipitation (mm), 2000–2050



Source: Nelson et al., 2009

Figure 6.: Change in precipitation (mm), 2000–2050



Source: Nelson et al., 2009

Figure 5 and 6 show changes in average precipitation. Each figure represent different scenario and illustrate the range of potential climate outcomes. The National Center for Atmospheric Research (NCAR) has noticeable higher average maximum temperatures than does Commonwealth Scientific and Industrial Research Organization (CSIRO). There is also difference between precipitation changes in Amazon. While NCAR scenario shows decline of precipitation in the eastern part, the CSIRO scenario expect declines in western part. As shown in the Figures, there are also very different results in Sub-Saharan and South Africa (Nelson et al., 2009). Author´s opinion is that highly constant results in CSIRO and NCAR scenario represent Zambian territory. But in the CSIRO scenario it is recognizable that north and northwest regions of Zambia has highly decline of precipitation.

According to Climate Change - Impact on Agriculture and Costs of Adaptation document (2009) climate change will have some indirect effects on irrigated crops through direct impact on internal renewable water (IRW). This water is formed from the precipitation. Authors of both scenarios predict more precipitation over land, but in addition climate change will bring higher temperatures. This will increase the water requirements of crops. Irrigation water supply reliability (ISWR), which express ratio of water consumption to requirements of crops, improves under the NCAR scenario and worsens under the CSIRO scenario in developing world. The irrigated yield losses are higher under the CSIRO scenario than the NCAR scenario. Specific yield losses in developing countries for important crops can be seen in Table 7. (Nelson et al., 2009)

Table 7: Climate-change induced yield effects by crop and management system, % change from yield with 2000 climate to yield with 2050 climate.

Crop	CSIRO No CF	NCAR NO CF	CSIRO CF	NCAR CF
Maize, irrigated	-2.0	-2.8	-1.4	-2.1
Maize, rainfed	0.2	-2.9	2.6	-0.8
Rice, irrigated	-14.4	-18.5	2.4	-0.5
Rice, rainfed	-1.3	-1.4	6.5	6.4
Wheat, irrigated	-28.3	-34.3	-20.8	-27.2
Wheat, rainfed	-1.4	-1.1	9.3	8.5

Source: Nelson et al., 2009

Note: CF = with CO2 fertilization; No CF = without CO2 fertilization.

According to Climatic Change in Zambia (2010) prepared by Mweembe Muleya Mudenda the negative impacts of climate change has already occurred in Zambia. Droughts and floods are major challenges to the country (table 8). The weather patterns become unstable and floods come almost every rain season. This became devastating to the Zambian economy and development. Floods are thus becoming another threat to farmers, whose crop is washed away. And it is also threat to food security (Mudenda, 2010). In the last twenty years, frequency of droughts in Zambia has also increased. The droughts of 1991/92, 1994/95 and 1997/98 worsened the quality of life for some social groups such as smallholders.

Table 8: Main impacts of climate hazards

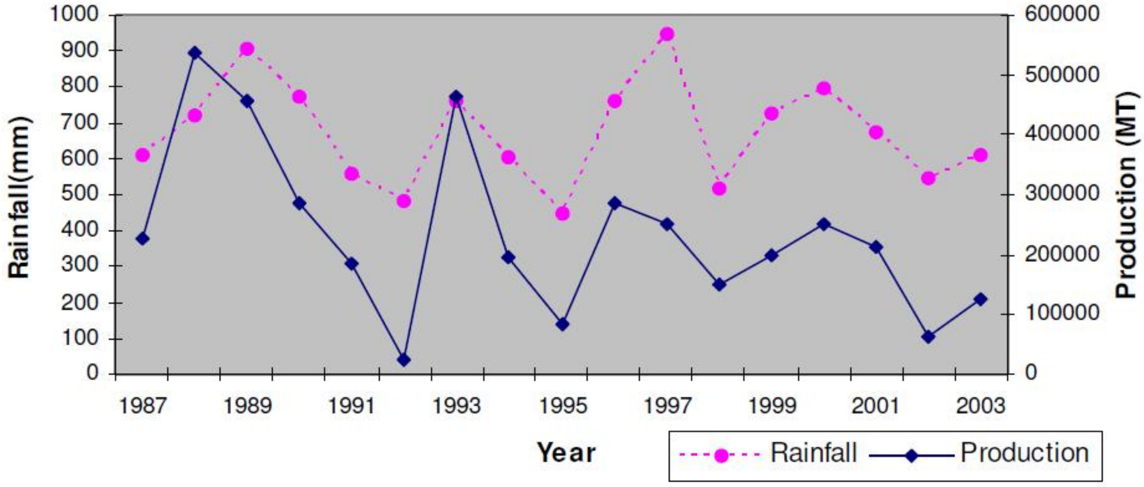
Drought	Floods	Extreme Heat	Shorter Rainy Season
• Crop damage/loss leading to food scarcity and hunger • Water shortages • Reduced fish stocks • Income loss • Increase in diseases (affecting humans and animals) • Decreased water quality • Increased soil erosion • Decreased soil fertility • Increased honey production (if drought is not too severe)	• Crop damage/loss, leading to food scarcity and hunger • Loss of crop land and grazing ground • Decline in fish catches • Increase in diseases (malaria, dysentery, cholera, etc.) • Destruction of infrastructures (houses, roads) • Life loss (humans and livestock) • Interference with energy production due to change in water flows	• Loss of life • Increase in diseases affecting animals, crops and humans (especially malaria) • Decreased human capacity to do work • Loss of life (animals and humans) • Crop damage/loss • Reduced fish stocks • Decreased livestock feed • Reduced water quality	• Increase in risk of crop failure • Crop damage/loss • Decreased income from crop selling for those with reduced production • Crop seeds do not reach maturity (which negatively affects the next crop generation) • Reduced forest regeneration

Source: Nyambe and Feilberg, not dated

Over the last thirty years, 32 meteorological stations in Zambia detected the change in temperature. The mean temperatures computed for the agro-ecological zones (see page 7) indicate that the summer temperature in Zambia is increasing at the rate of about 0.6°C per decade. That is about ten times higher than southern African rate or the global or southern temperature rate (Wit M. 2006).

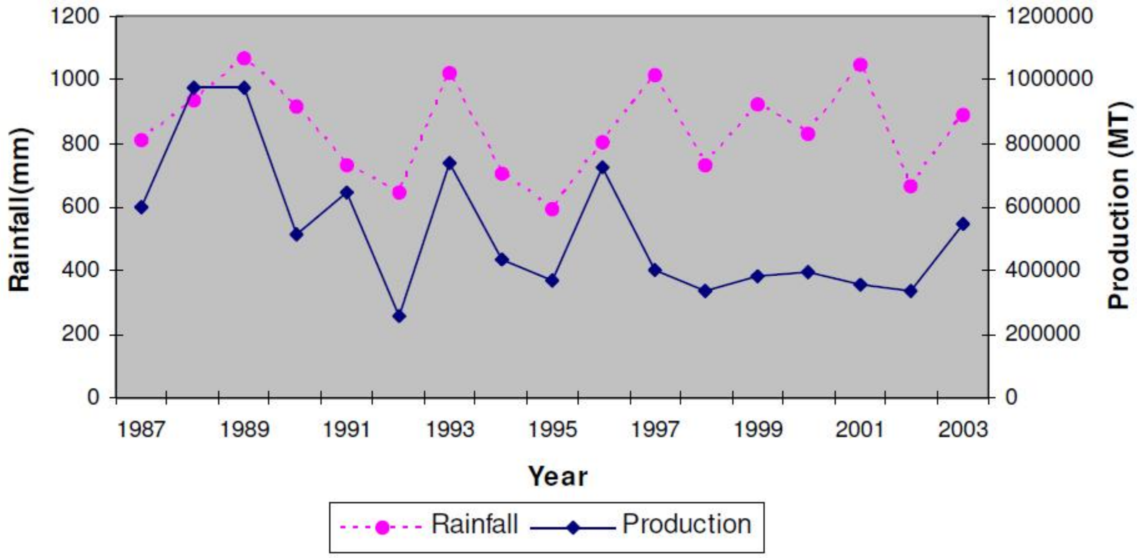
Data calculated annual precipitation from the period between 1190/1191 to 2003/2004 show significant anomalies in Zambia. At least 10 years, rainfall was below normal limit in each agro-ecological zone (Figure 3). Significant precipitation deficiencies in important growth stages of crops led to a deficit in crop production. This is a crucial issue for Zambia, whose agriculture is largely dependent on rainfall. As may be seen from figure 7 and 8, the yield of maize in the mentioned provinces shows a high correlation with total seasonal rainfall (Wit M. 2006).

Figure 7.: Rainfall and Maize production for Southern province



Source: Wit M. 2006

Figure 8.: Rainfall and Maize production for Central and Eastern Provinces



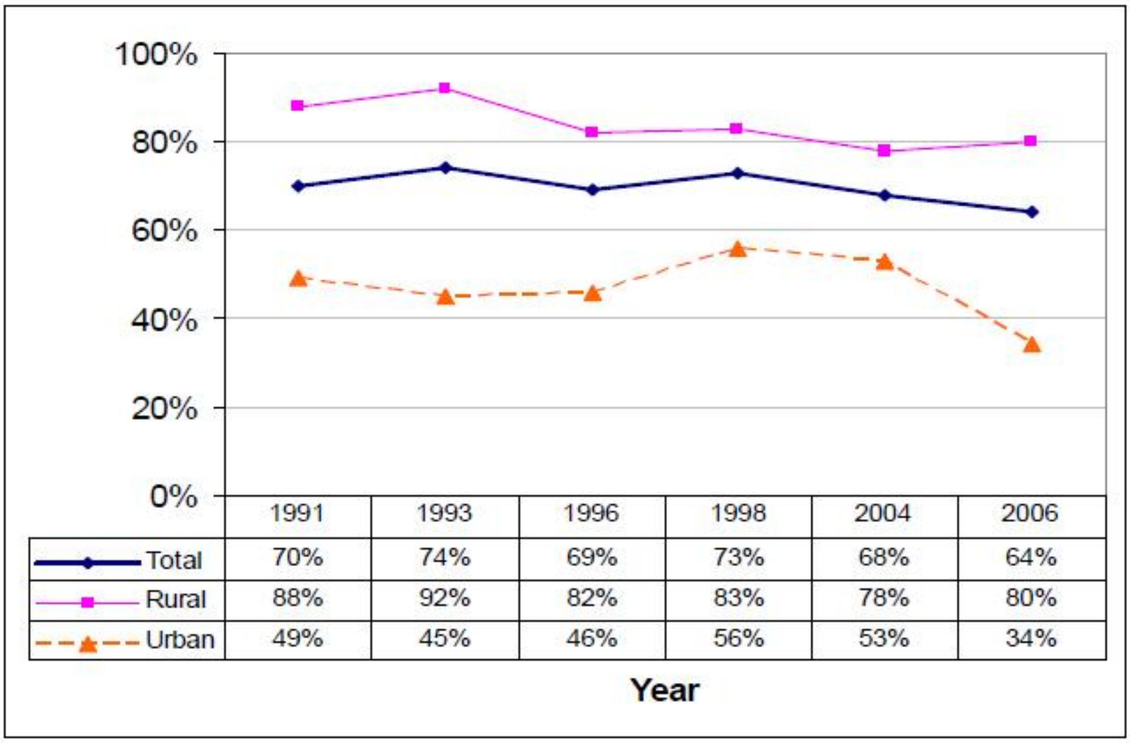
Source: Wit M. 2006

2.4 Food security in Zambia

Population growth, expansion of urban areas and no significant progress in agricultural production contributes to food shortages in the regions of southern Africa. Finding the new technologies and processes in agriculture is essential for fostering economic growth and strengthens food security. Zambia is a country where agriculture is a significant source in the fight against poverty. But it is also breadbasket of South Africa. Compared with the other countries, Zambia has large amounts of fertile land and water. Despite this good background, agricultural growth in Zambia stagnates and poverty of rural population remains high. There is also malnutrition that disproportionately affects rural Zambians.

While the overall poverty rate in the country has decreased, poverty of Zambian rural population remains enormously high. About 80 % people residing in rural areas live in poverty. Moreover rural children often show signs of stunting and underweight. Distribution of people living in enormous poverty is very different. People living in outlying regions experiencing a higher incidence of extreme poverty than those who live in more accessible regions closer to line of rail.

Figure 9.: Poverty Levels in Zambia, 1991 to 2006



Source: Sitko at al., 2011

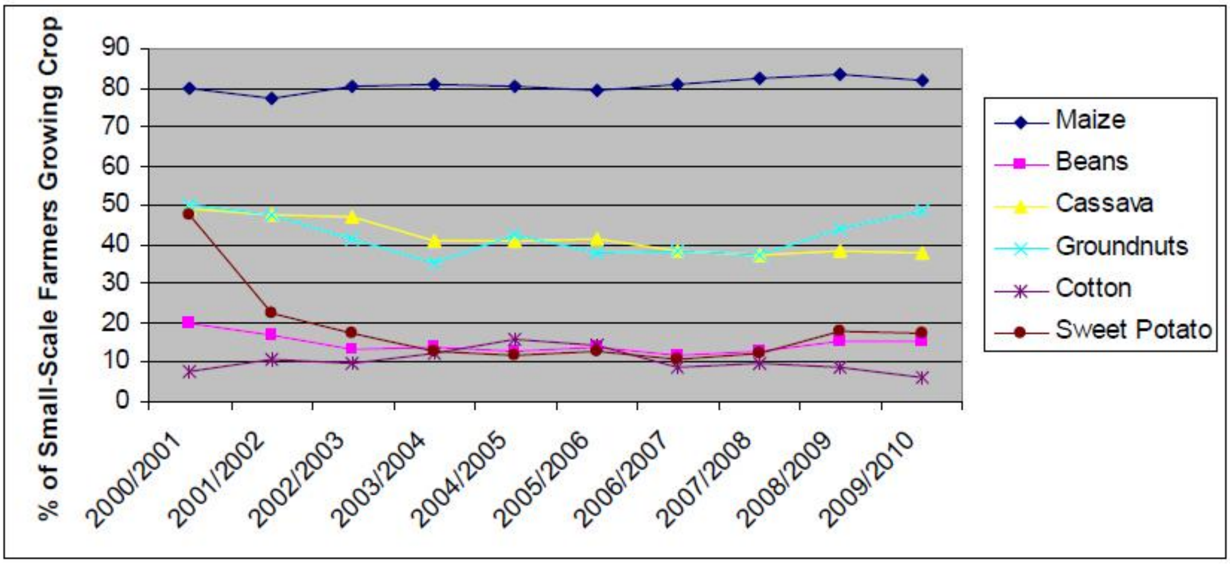
As may be noticed on Figure 9, poverty is markedly higher in rural areas than in urban areas. There is also slightly increase in poverty in 2006 compared to 2004 in rural areas, but a large decline in urban areas.

Food insecurity in Zambia is mainly caused by malnutrition. Only 36 % of households have enough food to eat and 19 % rarely or never have enough food to eat. These people are categorized as chronically food insecure. These data are consistent with data indicating that 64%

of Zambia's population lives below the global poverty and that 36.5 % live in extreme poverty. Nearly half of Zambian rural population has daily caloric intakes below 1,750 per day (daily requirement is 2, 750 for men and 2, 600 for women) and their households spend almost 80 % of their budget on food. About half the total number of households (51 %) could afford two meals and 5 % can only have one meal a day.

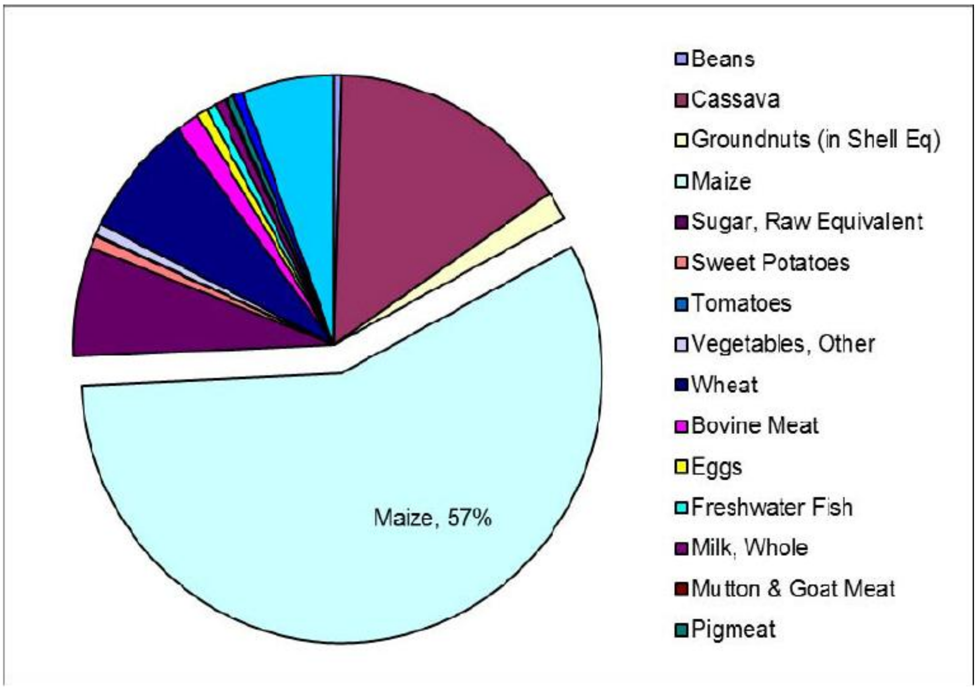
As may be noticed from figure 10, The Maize is overwhelmingly dominated crop of small-scale farmers. Maize is also a major source of daily caloric consumption (figure 11). On other hand, groundnuts are often use like intercrop with maize and it is the second most widely cultivated crop in Zambia. Groundnuts are also very important source of protein in Zambian diets (Siamusantu S et al., 2009).

Figure 10.: Percent of small-Scale Farmers Growing Crop by Year



Source: Sitko at al., 2011

Figure 11.: Zambia's energy consumption per Capita and Day (by Crop, 2008)



Source: Sitko at al., 2011

2.5 Artificial recharge of ground water

Artificial recharge to ground water can be describe as the method of water recharge that take place when the structure of nature is purposely and artificially modified to increase recharge. What is artificial is not recharge itself but management of surface water supply. This surface water supply can be transferred to the aquifer by human interference. Recharge of aquifer is enabled trough percolation of surface water, which in normally conditions does not percolate into the aquifers. This augmenting of the natural replenishment of ground water storage is provided by several methods of construction.

There are many reasons why used artificial recharge methods to place water into aquifers. Major projects of artificial recharge have purpose in replenishing ground water resources in dried-up aquifers and to preserve water. The benefits and advantages of artificial recharge can be described as follow:

- Subsurface storage space is available free of cost.
- Evaporation losses are negligible.
- Quality improvement by infiltration through the permeable material.
- Biological purity of replenished groundwater is very high.

- Artificial recharge has no negative impacts such as endanger the environment or population (Chatterji, 2007).

According to Groundwater Economics (2010) the benefits of aquifer recovery are as follow:

- Using the transmission and treatment capacities of the subsurface environment.
- Management of subsidence and saltwater intrusion.
- Avoided costs of alternative water supply during drought.
- Avoided impacts to communities during water shortages.
- Conjunctive management of ground and surface waters (Job Ch, 2010)

According to Artificial recharge for conjunctive use in Irrigation (2001) there are several methods of artificial recharge. They are divided into 4 broad categories:

1. Direct surface methods.
2. Direct subsurface methods.
3. Combination of surface and sub-surface methods.
4. Indirect methods.

Direct surface methods are the oldest and simplest methods. This method is based on percolation of water from surfaces through the soil to an aquifer. These methods include flooding, ditch and furrow, basins, stream channel modification, stream augmentation and over-irrigation technique. It is recommended use these methods for irrigation purposes because these methods are low-cost.

Direct subsurface methods are methods which use direct convey into aquifer. The techniques of direct subsurface method include injection of water to aquifer, pits, shafts or well. The advantage of these techniques is in lesser evaporation due to smaller surface area. But there is disadvantage in quality of water. Supply of water must be purified before injecting into the ground because prevention of clogging.

Examples of combination of surface and sub-surface method are drainage collectors with wells or basins with pits. These combinations can be used to meet specific recharge objectives (Chatdarong, 2001)

3 Hypothesis and Objective

3.1 Hypotheses

Hypothesis 1: Recharge well can provide potential volume of water required in irrigation for growth of specific crop.

Hypothesis 2: Check dam or percolation tank can provide potential volume of water required for growth of specific crop.

Hypothesis 3: Spreading Channel can provide potential volume of water required in irrigation for growth of specific crop.

3.2 Main Objective

The main objective of this thesis is to analyze feasibility of supplying irrigation of main food staples with groundwater, which has been artificially recharged by specific methods. These methods include recharge groundwater using Recharge tube wells, using Check Dams, Percolation Tanks and finally spreading channels. The main crops were chosen those that are specific for Zambian agriculture and also are important for assuring of food security in Zambia. From another point of view, the main objective is study on establishment of artificial ground water recharge for irrigation as an opportunity to contribute Zambian sustainable rural development.

3.3 Specific Objectives

There are three main hypotheses which are based on different combinations between selected crops and artificial recharge methods. Specific objectives have been formulated in tune with hypotheses and define steps towards meeting the main objective as specified in 3.2. The concern types of crops which were selected according to the importance they have in Zambian agriculture.

Specific Objective 1: This objective is focused on determination of irrigation potential provided by recharge well. There are several combinations of technical parameters and number of days of recharge. Through every calculated result is determined if recharge well with specific parameters and number of days of recharge can provide potential volume of water required in irrigation for growth of specific crop. If there is a recharge well, which could supply all crops separately - hypothesis is confirmed.

Specific Objective 2: This objective is focused on determination of irrigation potential provided by check dam or percolation tank. There are several combinations of technical parameters like material of bedrock and average water spread area. Through every calculated result is determined if check dam or percolation tank with specific parameters can provide potential volume of water required in irrigation for growth of specific crop. If there is a check dam or percolation tank, which could supply all crops separately - hypothesis is confirmed.

Specific Objective 3: This objective is focused on determination of irrigation potential provided by spreading channel. There are several combinations of technical parameters like material of bedrock and total wetted perimeter for full length of spreading channel. Through every calculated result is determined if spreading channel with specific parameters can provide potential volume of water required in irrigation for growth of specific crop. If there is a spreading channel, which could supply all crops separately - hypothesis is confirmed.

4 Methodology

The main procedure which was used in this thesis was mathematically analyze as to amount of water required to total grow of specific crop. The mathematical analyzes has got two parts which each has different purpose. Five staple and commercial crops were selected for the potential analyses.

4.1 Crops Selected

Following crops were selected because they represent main nutrition base or main commercial base for Zambian population.

- Maize
- Sugarcane
- Peanuts
- Sorghum
- Cotton

Each of the crops is cultivated on specific area and irrigated by water from specific artificial recharge method.

4.2 Methods of Artificial Recharge of Ground Water

There are three artificial structures used in this thesis. They are:

- Recharge wells
- Check dams and Percolation Tanks
- Spreading Channel

4.2.1 Recharge wells

Artificial recharge by recharge wells is mainly used for expanding the groundwater storage in deeper aquifers. Routed supply of water replenishes an aquifer either under pressure or gravity. Replenished water can be subsequently used to irrigation (Chatterji, 2007).

4.2.2 Check dams and Percolation Tanks

Check dams are mainly constructed to stop flow of surface water in the stream channels. The retained water remains on pervious soil or rock surface and then it is recharged. Percolation Tanks are constructed on similar principles. The main principle of Percolation Tank is creation of surface water body covering a highly permeable land area. The runoff is made by percolation, from which comes recharge of the ground water storage (Chatterji, 2007).

4.2.3 Spreading Channels

Spreading channels can be used in valleys where streams flow through. Original runoff riverbed can be extended for increase of the streambed area and slowing down stream flow. These modifications are mainly designed to increase ground water recharge seasonally in arid and semi arid regions where are areas with deep water tables (Chatterji, 2007).

4.3 Mathematical calculation of water amount required for irrigation

This part of thesis focuses on calculating quantity of water required for Irrigation. Key elements of this part are based on document Irrigation Water Management: Irrigation Water Needs which was published by FAO (1986). There are calculations for each of the selected type of crop in Zambian conditions. The results are subsequently used in final comparison.

First step in calculation of irrigation water need is determination of crop evapotranspiration (mm/day). For this purpose was used theoretical calculation, namely the Blaney-Criddle method, using measured climatic data. This method is simple one using only measured data of temperature, so it should be noted that calculation is not very accurate. It provides rough results. The Blaney-Criddle formula was compiled:

$$ETo = p * \ 0.46 * T_{mean} + 8 \ \ (1)$$

T_{mean} – mean daily temperature [°C]

p – Daily percentage of annual daytime hours

ETo – Crop evapotranspiration [mm/day] as an average for a period of 1 month

If there are no average temperatures, it can be used calculation of Mean daily temperature as follows:

$$T_{max} = \frac{sum\ of\ all\ T_{max}\ values\ during\ the\ month}{number\ of\ days\ of\ the\ month}$$

$$T_{min} = \frac{sum\ of\ all\ T_{min}\ values\ during\ the\ month}{number\ of\ days\ of\ the\ month}$$

$$T_{mean} = \frac{T_{max} + T_{min}}{2}$$

For determination of Daily percentage of annual daytime hours was used knowledge of approximate latitude of the location (In this case it was Lusaka, Zambia - 15° Latitude). From this fact and table x (see annex) were determined final data for every month.

Next step deals with factors of crop type and four growth stages. These factors influence crop water needs. “The reference grass crop and the crop actually grown are given by the crop factor – Kc” (Brouwer and Heibloem, 1986).

Formula for specific crop evapotranspiration follows:

$$ET_{crop} = ET_0 * K_c (2)$$

ET_{crop} – specific crop evapotranspiration [mm/day]

Kc – crop factor

ETo - Crop evapotranspiration [mm/day]

The crop factor depends on:

- The type of crop
- The climate
- The growth stage of the crop

There are four growth stages of crops – Initial stage, Crop development stage, Mid-season stage and late season stage. For each of this stage is different crop factor and duration depending on crop type.

Table no. 9 shows crop factors for chosen crops.

Table 9.: Kc values (for sugar cane see Tab. 10)

Crop	Initial stage	Crop dev. stage	Mid-season stage	Late season stage
Maize	0.40	0.80	1.15	1.00
Sugarcane	Special*	Special*	Special*	Special*
Cotton	0.45	0.75	1.15	0.75
Peanut/Groundnut	0.45	0.75	1.05	0.70
Sorghum	0.35	0.75	1.10	0.65

Source: Brouwer and Heibloem, 1986

* - For Sugarcane special Kc values were used. These values depend on factors like:

- Wind
- Humidity

For the purposes of this work was used ratoon sugarcane whose growth stage takes 12 months.

Table 10.: Kc values for Ratoon sugarcane

Growth stage (months)	Kc values
0-1	0.6
1-2	0.85
2-4	1.1
4-10	1.15
10-11	0.82
11-12	0.65

Source: Brouwer and Heibloem, 1986

Duration of growth, divided into the four stages, is shown in table 9. Values of crops were taken directly from Irrigation Water Management: Irrigation Water Needs (1986) and are shown in table 11.

Table 11.: Indicative values of the total growing period

Crop	Total	Initial stage	Crop dev. stage	Mid-season stage	Late season stage
Maize	110	20	30	50	10
Sugarcane	Table no. 9	Table no. 9	Table no. 9	Table no. 9	Table no. 9
Cotton	195	30	50	65	50
Peanut/Groundnut	140	30	40	45	25
Sorghum	130	20	35	45	30

Source: Brouwer and Heibloem, 1986

Note: For the purposes of this work were chosen maximal total growing periods of crops

The following step deals with inconsistency of Kc values and number of days in the month that a given stage takes. ET_{crop} has to be determined on the monthly basis, so it is important to specify the Kc on the monthly basis. The formula for this step is done as follows:

$$Kc\ month = \frac{x_1}{30} * Kc_I + \frac{x_2}{30} * Kc_2 + \cdots \frac{x_n}{30} * Kc_4 (3)$$

x_n – number of days in particular stage

Kc_n - crop factor for particular stage

After the calculation of Kc on monthly basis, comes the calculation of crop water need for day in every month [mm/day].

$$ET_{crop} = ET_0 * Kc_n\ (4)$$

From this result, it can be easily determined quantity of water needed for month of grow

$$ET_{crop-m} = 30 * ET_{crop}\ (5)$$

ET_{crop-m} - crop water needs [mm/month]

Note: It is assumed that all months have 30 days

For calculation of Irrigation water need is required determination of the effective rainfall, which is retained water used by plant roots after the portion of water runoff, evaporate from soil and percolate deep to the ground. It is also called effective part of rainwater and it is formulated as follow:

$$Pe = 0.8 * P - 25\ if\ P > \ 75 \frac{mm}{month} (6)$$

$$Pe = 0.6 * P - 10\ ifP < \ 75 \frac{mm}{month} (6)$$

P – rainfall of precipitation [mm/month]

Pe – effective rainfall [mm/month]

Note: $\boldsymbol{Pe \geq 0}$

Finally it can be determined Irrigation water need for crop from following formula:

$$IN = ET_{crop-m} - Pe\ (7)$$

IN – Irrigation water need for crop [mm/month]

For the purposes of this work, there are no less important calculations for determination required water in cubic content. First of all there is a sum of all irrigation water needs in every month.

$$IN_y = \sum_{n=1}^{max=12} IN_1 + IN_2 + \cdots IN_n \ (8)$$

IN_y – Irrigation water need for all months of crop growth [mm]

In the second step, it is calculated amount of water for specific field area.

$$V = IN_y * S \ (9)$$

V – Volume of water [m^3]

S – Area of crop field [m^2]

IN_y - [m]

4.4 Mathematical calculation of water amount potential recharged by artificial recharge methods

The main content of this part focuses on calculating quantity of water potentially recharged by several methods. These calculations estimate upper limits of quantities of recharge through each artificial recharge structure based on studies carried out in different hydro-geological set-ups. Recharge estimates are in general form with field examples from alluvial unconfined/semi confined aquifer systems. The key document which was used for calculation was the Manual on Artificial Recharge of Ground Water (2007) published by Ministry of water resources in India.

First calculation of this chapter was estimation of water volume recharged by Check Dams and Percolation tank. Formula for water recharge is:

$$P = \frac{a * 10000 * b * 3600 * 24 * c}{10^6 * 10^6}$$

P – Quantity of induced recharge [MCM]

a – Average water spread area [Hectares]

c – Inflow and storage period [Days]

b – Seepage rate [Cu m/sec/million sq of wetted perimeter]

This formula was modified for the purpose of this study. Seepage rate was exchange with Hydraulic conductivity (Todd and Mays, 2005) for easier handling with representative values of Hydraulic conductivity. Modified formula is as follows:

$$Q = a * K * t \ (10)$$

Q – Quantity of induced recharge [m^3]

a - Average water spread area [m^2]

K - Hydraulic conductivity [m*day-^{1}]

t - Inflow and storage period [Days]

Second calculation of this chapter was estimation of water volume recharged by **Spreading channel.** Formula for water recharge is:

$$q = \frac{a * 10000 * b * 3600 * 24 * c}{10^6 * 10^6}$$

q – Quantity of induced recharge [MCM]

a – Total wetted perimeter for full length of spreading channel [Hectares]

c – Availability of water channel [Days]

b – Seepage rate [Cu m/sec/million sq of wetted perimeter]

Like in the previous calculation, the formula was modified and is as follows:

$$Q = a * K * t \ (11)$$

Q – Quantity of induced recharge [m^3]

a - Total wetted perimeter for full length of spreading channel [m^2]

K - Hydraulic conductivity [m*day-^{1}]

t - Availability of water channel [Days]

Table 12.: Representative values of Hydraulic Conductivity

Material	Hydraulic conductivity [$m*day^{-1}$]	Type of measurement
Gravel, medium	270	R
Sand, medium	12	R
Dolomite	0.001	V
Clay	0.0002	H
Limestone	0.94	V
Schist	0.2	V
Granite, weathered	1.4	V
Basalt	0.01	V

Source: Todd and Mays, 2005

Note: H is horizontal Hydraulic Conductivity, R is a repacked sample, and V is vertical Hydraulic Conductivity.

Table 12 shows Representative values of Hydraulic Conductivity.

Third calculation of this chapter was estimation of water volume recharged by Recharge tube well. Formula for water recharge is:

$$R = \frac{a * 86.4 * b}{10^6} \quad (12)$$

R – Quantity of recharge [MCM]

b – Number of days of recharge [days]

a – Injection recharge rate [liters per second]

4.5 Comparison of results

In the final part of the work are presented and compared results. From these comparisons are subsequently confirmed or rejected hypotheses. Consequently, a discussion is held on, resulting recommendations and final statements about positives and negatives of potential implementation of artificial recharge structures.

4.6 Conclusions and Recommendations formulation

On basis of the two mathematical calculation methods the hypotheses were confirmed or rejected. This was used as the first part of the conclusions. The second part is focused to more general problems linked to food security and water management in Zambia.

5 Results and Discussion

5.1 Results of water amount required for irrigation

In this chapter are shown results of water amount required for irrigation. There are five results for five chosen crops:

- Maize
- Sugarcane
- Peanuts
- Sorghum
- Cotton

The meteorological data (average temperature, Rainfall of precipitation) for calculation was taken from Lusaka meteorological station ((Latitude 15 19S; Longitude 028 27E) and Kasisi Mission (Latitude 15 19S; Longitude 028 27E) throught meteorological website http://www.weatherbase.com/.

Beginning of growth of crops was estimated from references as follow:

- Maize – 1. May (Association for international collaboration of Agriculture and Forestry, 2008)
- Sugarcane – 1. May (Cornland D et al. 2001)
- Cotton – 15. November (Chitah K, 2010)
- Peanut/groundnut – all season (National Smallholder Farmers Association of Malawi, Not Dated)
- Sorghum – 1. January (Oyama, 2007)

In the case of maize, there is decision that it will be grown in dry season. Main reason for this decision is following: “Zambia has clear rainy and dry seasons. Vegetables are cultivated in the dry season, from May to October, while maize and other cereals are grown in the rainy season, from November to April. Although rain-fed cultivation prevails for maize, it is also grown in the dry season where irrigation facilities are available” (Association for international collaboration of Agriculture and Forestry, 2008).

Area of one hectare was chosen from data of Food security research project document (2011), from information that “roughly 420,000 rural households, or 30.5% of all rural households in Zambia, farm on 1 hectare of land and continue to grow maize” (Sitko N, 2011).

For better understanding of procedure, there is an example of calculation for Maize

1. Calculation of ETo for May (1):

$$ETo = 0.26 * \ \ 0.46 * 18 + 8$$

$$ETo = 4.233 \text{ mm/day}$$

2. Calculation of crop factor for May (3):

$$Kc\ may = \frac{20}{30} * 0.40 + \frac{10}{30} * 0.80 = 0.534$$

3. Calculation of crop evapotranspiration for May (4):

$$\text{ETcrop} = 4.233 * 0.534$$

$$\text{ETcrop} = 2.260 \text{ mm/day}$$

4. Calculation of quantity water needed for May (5):

$$ET_{crop-m} = 2.260 * 30$$

$$ET_{crop-m} = 67.81\ mm/month$$

5. Calculation of effective rainfall for May (6):

$$Pe = 0.6 * 3 - 10$$

$$Pe = -8.2$$

$$Pe \neq -8.2 => Pe = 0\ mm/month$$

6. Calculation of Irrigation water need for May (7):

$$IN = 67.81 - 0$$

$$IN = 67.81\ mm/month$$

7. Sum of all irrigation water needs in every month (8):

$$IN_y = 67.81 + 44.12 + 137.8 + 105.78$$

$$IN_y = 3555.51\ mm$$

8. Calculation of total volume of water required for irrigation of 1 hectare of Maize field per season (9):

$$V = 0.3555 * 10\ 000$$

$$V = 3555\ m^3$$

The whole procedure of calculation and arrangement of the growing seasons are shown in table 14 (example of calculation results for maize) Irrigation water need for all crops are shown in table 12. All calculation results concerning crop irrigation need are included in the annex.

Table 13.: Irrigation water need

Crop	**Irrigation water need for one hectare [m^3]**
Maize	3555
Sugarcane	12193.211
Cotton	3556.259
Peanut/Groundnut	7714.727
Sorghum	2115.05

Discussion of Results

It is apparent (see Tab. 13) that the highest irrigation need is for sugar cane (12193.211 m^3) and the lowest for sorghum (2115.05 m^3). The irrigation need of maize is also not very high (3555 m^3). From the point of view of water consumption it seems that the sorghum and maize growth is more environmentally friendly in Zambian conditions. Sugarcane, like commercial crop, is very demanding. Author´s opinion is that even ratoon sugarcane is better to cultivate by commercial farmers and concentrate effort on another commercial crop – which is cotton. It also seems that Maize grown in dry season is undemanding of water consumption and if there is potential of irrigation, it could be easily grown in dry seasons.

Table 14.: Maize irrigation water need in Zambian condition

Maize	Measures	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Average Temperature	°C	22	22	22	21	18	16	16	18	22	25	24	22
mean daily percentage of annual daytime hours		0,29	0,28	0,28	0,27	0,26	0,25	0,26	0,26	0,27	0,28	0,29	0,29
Crop evapotranspiration	mm/day	5,255	5,074	5,074	4,768	4,233	3,840	3,994	4,233	4,892	5,460	5,522	5,255
Growth stages						I-II	II-III	III	III-IV				
Kc per Month						0,53	0,383	1,15	0,833				
Crop water need	mm/day					2,26	1,47	4,59	3,53				
Crop water need	mm/month					67,81	44,12	137,78	105,78				
Rainfall of precipitation	mm/month					3	0	0	0				
Effective Rainfall	mm/month					0	0	0	0				
Irrigation water need	mm/month					67,81	44,12	137,78	105,78				

5.2 Results of water amount recharged by Artificial recharge methods

This part of work is focused on results of potential volume of water recharged by mentioned methods. The data (materials, areas and injection recharge rates) for calculation was considered from documents dealing with topic of artificial water recharge. Mainly from Manual on Artificial Recharge of Ground Water (2007) and Guide on artificial recharge to ground water (2000). Inflow and storage period was determined on one hundred days. This option was made from the observation that rainy season in Zambia is from November to March (Safari Consultants - When to Travel & Seasons, Not Dated). But the most powerful rainy season is from December to February (table 18 - Rainfall of precipitation). Effectiveness for percolation tanks, check dams and spreading channels was determined on 49.6 %. This average effectiveness is considered like precedent from Jeur Sub-basin Ahmednagar District, Maharashtra (Ministry of water resources, 2000).

There is an example of calculation for percolation tank of these parameters:

- Material – Dolomite (0.001 $m*day^{-1}$)
- Average water spread area – 30 000 m^2
- Inflow and storage period - 100 days
- Effectiveness - 49.6 %

$$Q = \frac{(30000*0.001*100)}{1000000} * 0.496 \quad (10)$$

$$Q = 0.0015\ MCM$$

There is an example of calculation for Recharge tube well of these parameters:

- Average injection recharge rate – 8 liters per second
- Number of days of recharge - 100 days

$$R = \frac{8 * 86.4 * 100}{10^6} \quad (11)$$

$$R = 0.0691\ MCM$$

All results for Check Dams and Percolation tanks, Spreading channels and Recharge tube wells are shown in Table 15, Table 16 and Table 21.

Table 15: Potential volume of water recharger by percolation tanks and check dams in Million Cubic Meters

Check Dams and Percolation tank	Average water spread area [m^2]									
Material	**10 000**	**20 000**	**30 000**	**40 000**	**50 000**	**60 000**	**70 000**	**80 000**	**90 000**	**100 000**
Gravel, medium	133,9200	267,8400	401,7600	535,6800	669,6000	803,5200	937,4400	1 071,3600	1 205,2800	1 339,2000
Sand, medium	5,9520	11,9040	17,8560	23,8080	29,7600	35,7120	41,6640	47,6160	53,5680	59,5200
Dolomite	0,0005	0,0010	0,0015	0,0020	0,0025	0,0030	0,0035	0,0040	0,0045	0,0050
Clay	0,0001	0,0002	0,0003	0,0004	0,0005	0,0006	0,0007	0,0008	0,0009	0,0010
Limestone	0,4662	0,9325	1,3987	1,8650	2,3312	2,7974	3,2637	3,7299	4,1962	4,6624
Schist	0,0992	0,1984	0,2976	0,3968	0,4960	0,5952	0,6944	0,7936	0,8928	0,9920
Granite, weathered	0,6944	1,3888	2,0832	2,7776	3,4720	4,1664	4,8608	5,5552	6,2496	6,9440
Basalt	0,0050	0,0099	0,0149	0,0198	0,0248	0,0298	0,0347	0,0397	0,0446	0,0496

Table 16: Potential volume of water recharger by percolation tanks and check dams in Million Cubic Meters

Recharge tube well	Number of days of recharge [days]				
Average recharge rate [liters per second]	20	40	60	80	100
1	0,0017	0,0035	0,0052	0,0069	0,0086
2	0,0035	0,0069	0,0104	0,0138	0,0173
3	0,0052	0,0104	0,0156	0,0207	0,0259
4	0,0069	0,0138	0,0207	0,0276	0,0346
5	0,0086	0,0173	0,0259	0,0346	0,0432
6	0,0104	0,0207	0,0311	0,0415	0,0518
7	0,0121	0,0242	0,0363	0,0484	0,0605
8	0,0138	0,0276	0,0415	0,0553	0,0691
9	0,0156	0,0311	0,0467	0,0622	0,0778
10	0,0173	0,0346	0,0518	0,0691	0,0864
11	0,0190	0,0380	0,0570	0,0760	0,0950
12	0,0207	0,0415	0,0622	0,0829	0,1037
13	0,0225	0,0449	0,0674	0,0899	0,1123
14	0,0242	0,0484	0,0726	0,0968	0,1210
15	0,0259	0,0518	0,0778	0,1037	0,1296

Discussion of Results

It is apparent (see Tab. 15) that percolation tank or check dam whose permeable land area is highly hydraulic conductive has a better results. Best results has percolation tank whose permeable land area is formed by gravel. Such percolation tank or check dam, with average water spread area of 10 hectares, could recharge about 1 339 MCM per one hundred days. It also seems that structures with sand are also capable of efficient recharge. According to Zambia – National Water Resources Report for WWDR3 (not dated), Aquifer lithology of sand and gravel represent about 11.9 % of whole country. It is also necessary to pay attention to dolomite and limestone which are highly productive aquifers and include Upper Roan Dolomite and Kundelungu Limestone in Zambia. These aquifers are distributed in Copperbelt, Lusaka, North-Western and Central provinces and cities such as Lusaka, Ndola and Kabwe are located on them (Nyambe and Feilberg, not dated). It is apparent that structures with limestone subsurface have better potential to recharge larger volume of water to aquifer than structures with dolomite subsurface.

From results for recharge wells (see Tab. 16) it seems that it is better to keep higher recharge rate for less days of recharge than keep lesser recharge rate for more days. It is also necessary to mention that low recharge rates are mainly caused by clogging of recharge well (see page 48).

5.3 Comparison of results and Discussion

From the comparison of results it can be seen that all three hypotheses were confirmed. There is solution of full irrigation for all chosen crops. The comparison of the results also shows that in majority of cases artificial recharge methods can provide potential volume of water required for growth of specific crop. There are negative results for percolation tanks, check dams and spreading channels whose bedrock is made up by dolomite and clay. These materials have low conductivity (Todd and Mays, 2005) and so artificial recharge is on low level even if average water spread area or total wetted perimeter for full length of spreading channel has 100 000 m^2.

Percolation tanks check dams and spreading channel, which has same formula for calculation of estimates, have lowest positive results as follow:

- Gravel material, 1 hectare of spreading area or wetted perimeter, one hundred days of recharge.
- Sand material, 1 hectare of spreading area or wetted perimeter, one hundred days of recharge

- Limestone material, 1 hectare of spreading area or wetted perimeter, one hundred days of recharge
- Schist material, 1 hectare of spreading area or wetted perimeter, one hundred days of recharge
- Granite weathered , 1 hectare of spreading area or wetted perimeter, one hundred days of recharge
- Basalt material, 3 hectares of spreading area or wetted perimeter, one hundred days of recharge

From theses lowest positive results is seen that structures with clay and dolomite bedrock are not able to supply irrigation needs. All remaining structures are able supply irrigation water needs with lowest possible spreading area or total wetted perimeter except structures with basalt bedrock which needs 3 hectares of spreading area or wetted perimeter.

According to groundwater quality: Zambia (2001) published by British geological survey, Best aquifers are formed from Dolomite and limestone. These materials were both considered and in final result more suited material for artificial recharge was Limestone (British Geological Survey, 2001). According to Guide on artificial recharge to ground water (2000), there must be considered some important aspects of percolation tanks for applying on certain area:

- Hydro-geological studies and meteorological studies. Mainly analysis of Rainfall pattern, number of rainy days and evaporation rate.
- The water spread area should be on uncultivable land.
- The aquifer that is chosen for recharge should have sufficient thickness of permeable vadose zone to accommodate recharge.
- The area in which is used the artificial recharge of groundwater should have sufficient number of irrigation wells and cultivable land to develop the recharged water.

Selected area for construction of Check dams should have these conditions and aspect:

- The rainfall in a catchment area (Drainage basin) should be less than 1000 mm/annum.
- There should be land under cultivation and Irrigation downstream of check dams (Ministry of water resources, 2000).

According to Manual on Artificial Recharge of Ground Water (2007), there are other aspects for consideration:

- The stream bed for check dams should 5 to 15 meters wide and at least 1 meter deep.
- The availability of surplus runoff from rainstorms (in India –monsoon) should be sufficient to fill the percolation tank every year.
- The catchment area (Drainage basin) should be between 2.5 and 4.0 sq km for small tanks and between 5.0 and 8.0 sq km for larger tanks.
- Construction of the tank should be conditioned by the percolation capacity of the strata than the yield of the Drainage basin. To avoid a possibility of large evaporation, larger capacity tanks should be constructed only if hydraulic conductivity is proven to be good.
- In conditions of India, percolation tanks are normally designed for storage capacities between 2.26 and 5.66 MCM (Chatterji, 2007).

There also 14 negative results for Recharge tube wells.

- Recharge tube well with injection recharge rate 1 lps cannot supply irrigation water needs.
- Recharge tube well also cannot supply crops in case when injection recharge rate is 2 lps and number of day of recharge is up to sixty days.
- Recharge well also cannot supply crops in case when recharge rate is 3 lps and number of day of recharge up to forty days.
- Recharge well also cannot supply crops in case when recharge rate is 4, 5, 6, and 7 lps and number of day of recharge is 10 days.

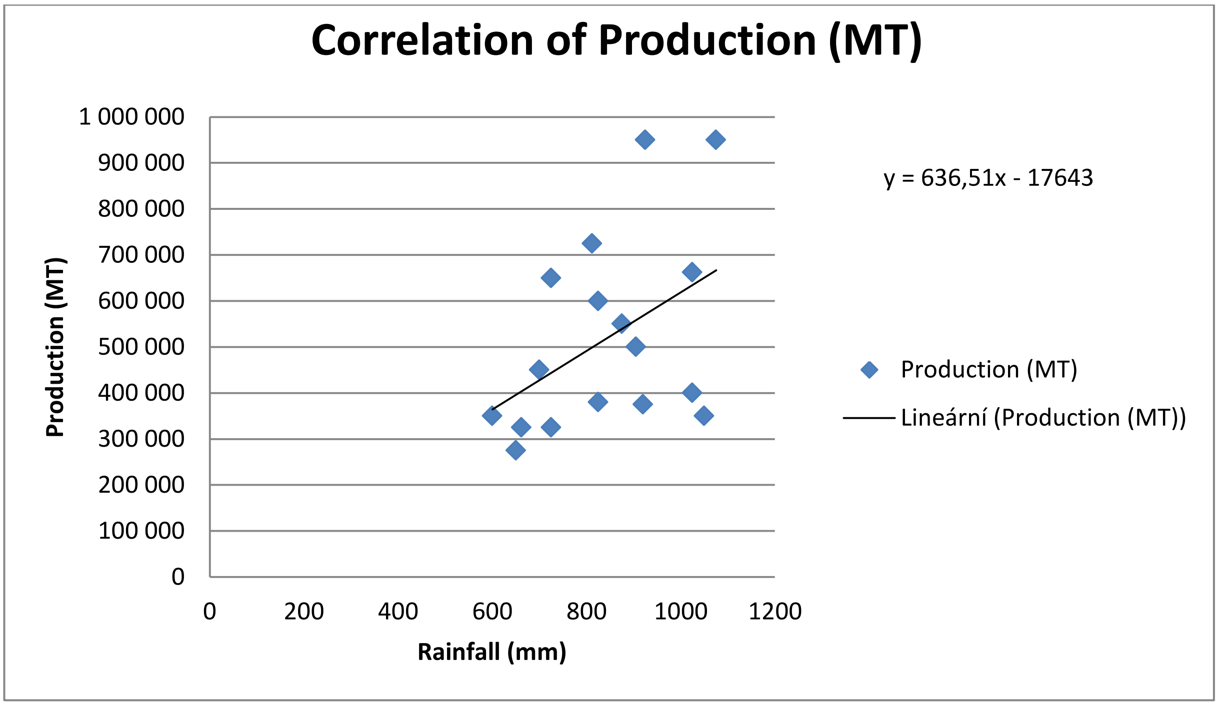
From experience recorded in Guide on artificial recharge to ground water (2000), the drastic low recharge rate (3 lps) was monitored due to clogging of injection well. Normal rate of recharge of Recharge tube well with inverted filter and without injection well ranges from 7 – 14 lps. Recharge tube well with injection well technique have very well efficiency. It goes even up to 15 lps at certain places (Ministry of water resources, 2000).

According to Manual on Artificial Recharge of Ground Water (2007), there are some design criteria for Recharge Wells that should be considered in condition of Zambia:

- A proper knowledge of the aquifer structure
- Proper attention should be taken that the water being used for recharge is not contaminated.
- For ideal benefits, it is appropriate to have Recharge wells cum pumping wells to groundwater recharge and extraction (Chatterji, 2007).

According to Zambia – National Water Resources Report for WWDR3, water sector will be influenced by climate changes causing the water stress in some areas and floods in others. So there will be need to improve water management and water suitability (Nyambe and Feilberg, not dated). The need of water for irrigation is visible from figure no. 12 that shows linear regression of Maize production and Rainfall for Central and Eastern Provinces. As may be noticed, there is a correlation between production of Maize and Rainfall. Coefficient of Correlation is 0.45 (modest dependence).

Figure 12.: Linear regression of Maize production and Rainfall for Central and Eastern Provinces



Note: Data of production and Rainfall were taken from figure 6.

Author of the thesis found that there is alternative method of recharge for dug wells and tube/bore wells. These wells can be used as recharged wells when source of water (rainy season) become available. This method can be used in areas where de-saturation of aquifers occurred due to over-exploitation of ground water. Dried-up dug well represent existing ground water abstraction structure that can provide cost effective artificial recharge of the deeper aquifer zone. There are also some design criteria and site characteristics for Gravity Head Recharge Wells:

- Surface water can be pumped into the dug well if phreatic aquifers remain unsaturated during rainy season.
- Wells with higher yields should be selected for recharge before low-yielding wells.

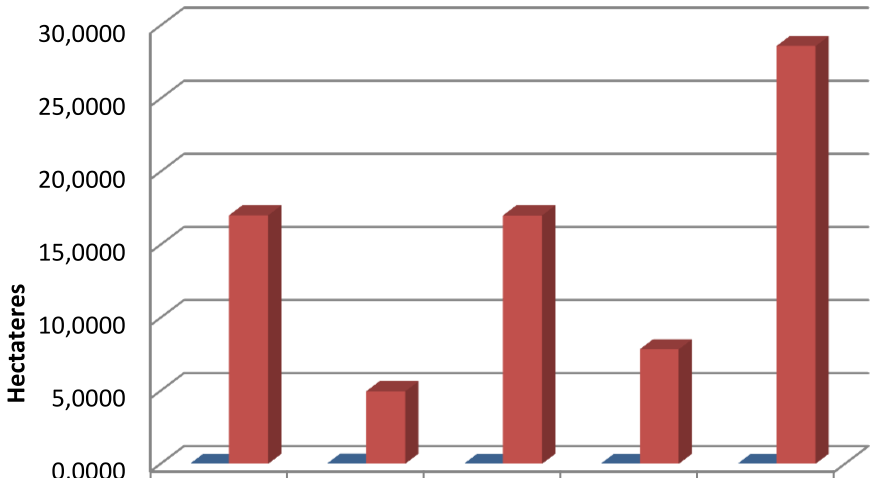
- The recharge head available in gravity head recharge wells is the elevation difference between the surface water level in the tank and the elevation of water table or hydraulic head. The recharge rates are much less compared to injection wells and also keep on reducing with build-up the water table in the de-saturated aquifer (Chatterji, 2007).

Author´s opinion is that this is suitable and cost-effective method for Zambian rural population.

The figure no. 13 shows estimates of irrigable area that is supplied by artificial ground water from Recharge tube well which recharge rate is 7 lps and aquifer is recharged during the one hundred days. As can be noticed Recharge tube well method has potential to mediate water for about 17 hectares of Maize or about 5 hectares of sugarcane in Zambian conditions etc. These estimates do not count with hydro-geological issues like storage capacity of aquifer and hydrological issues like runoff from Drainage basin.

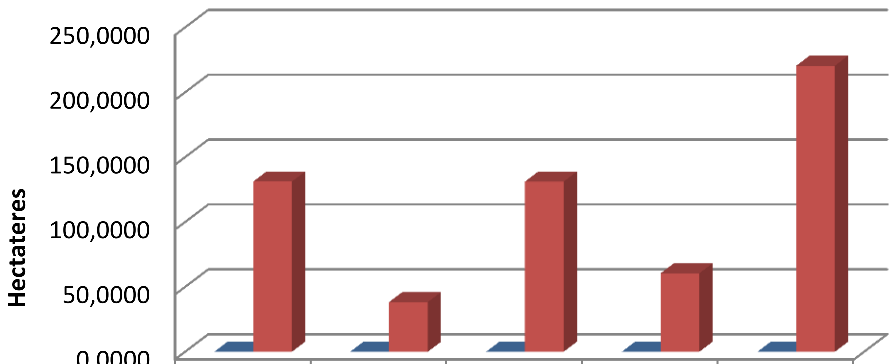
The figure 14 shows estimates of irrigable area that is supplied by artificial ground water from percolation tank or check dam with water spread area of 1 hectare, limestone subsurface and recharge duration of one hundred days. As can be noticed this structure has potential to mediate water for about 131 hectares of Maize or about 38 hectares of sugarcane in Zambian conditions etc. These estimates do not count with hydro-geological issues like storage capacity of aquifer and hydrological issues like runoff from Drainage basin.

Figure 13.: Hectares of potentially irrigable area by Recharge tube well.



	Maize	Sugarcane	Cotton	Peanut/ Groundnut	Sorghum
Irrigation water need for one hectare [MCM]	0,0036	0,0122	0,0036	0,0077	0,0021
Hectares of potentially irrigable area by Recharge tube well	17,0132	4,9601	17,0066	7,8396	28,5951

Figure 14.: Hectares of potentially irrigable area by percolation tank



	Maize	Sugarcane	Cotton	Peanut/ Groundnut	Sorghum
Irrigation water need for one hectare [MCM]	0,0036	0,0122	0,0036	0,0077	0,0021
Hectares of potentially irrigable area by Recharge tube well	131,1550	38,2377	131,1041	60,4351	220,4392

6 Conclusions and Recommendations

6.1 Conclusion

On basis of the reference analysis, acquired data processing and discussion the following conclusions have been formulated. First conclusions on hypotheses were conceived as resulting in their confirmation of rejection.

1. Hypothesis 1 “Recharge well can provide potential volume of water required in irrigation for growth of specific crop”. This hypothesis can be confirmed because there is positive results from which it is seen that recharge well can at certain circumstances supply water needs for irrigation of chosen crops.

2. Hypothesis 2 “Check dam or percolation tank can provide potential volume of water required for growth of specific crop”. This hypothesis can be confirmed because there is positive results from which it is seen that such structure can at certain circumstances supply water needs for irrigation of chosen crops.

3. Hypothesis 3 “Spreading channel can provide potential volume of water required for growth of specific crop”. This hypothesis can be confirmed because there is positive results from which it is seen that spreading channel can at certain circumstances supply water needs for irrigation of chosen crops.

4. The calculations conducted on water amount required for irrigation show that most demanding crop in Zambian condition is sugarcane which is mainly cultivated by commercial farmers. It also seen that Maize water needs in dry season are tolerable. Author´s opinion is that with suitable irrigation methods the cultivation of maize in dry season by small-scale farmers is possible.

5. The calculations conducted on artificial recharge show that there is high potential in water storage methods. With appropriate application in Zambian condition it could help establish sustainable development and food security.

6. Correlation of crop production and rainfall has been found positive and medium significant (Coefficient of Correlation - 0.45). It seems that Zambian agriculture is dependent on rainfall pattern.

7. Figure 11 and 12 show that example structures have potential to supply large area of cultivated crops in Zambian condition.

Situation in water management of Zambia is not very satisfying. Agriculture activities in Zambia are more and more depending on irrigation. Zambian government is aware of this problem and so proposes increase the utilization of water resources for development of irrigation schemes. This would suitably reduce dependence of agriculture on Rainfall. After all, Zambia is water-rich country, but it is also exposed to rotation of rainy season and dry season. There is also influence of climate changes which could cause increase of droughts and floods. According to Boreholes and Groundwater Recharging article (2011), every year more and more boreholes are being dug around the country to exploitation of groundwater. But after all, there is no evidence of sustainable development in water management.

Artificial recharge of groundwater is method commonly used in condition of India in times of monsoon. This method has high potential to make Zambian agriculture sustainable from view of water management. Efficiency of percolation tanks, check dams, spreading channels and recharge tube wells are extremely depend on rainfall pattern which is due rainy season acceptable.

This thesis is not try solve the irrigation problem in Zambia, but propose new wave of solution of food insecurity by artificial recharge methods. Confirmation of hypothesis shows that recharge methods have significant potential to contribute on sustainable irrigation.

6.2 Recommendations

1. As it was mentioned earlier, there are many problems which must be solved for future consideration of applying artificial recharge methods in Zambian conditions. First of all, there must be carried out case study for specific agriculture area, which has a potential for applying artificial recharge methods. Ratio of this potential must be determined by meteorological, hydrological and hydro-geological studies. There are specific needs for artificial recharge methods like rainfall of precipitation, total runoff of area, permeability of unconsolidated material of aquifer and storage capacity of aquifer. These factors significantly influence volume of water recharged by these methods. There must be also considered suitable system of irrigation wells connected to aquifers
2. There is also a different perspective and that is economic contribution to sustainable agriculture development. For future development of irrigation schemes must be considered return on investment. Contribution of recharge methods to total agriculture profit and lifetime of structures must be considered too.

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8 Annex

Table 17: Mean daily percentage (p) of annual daytime hours for different latitudes

Table 18: Sugarcane irrigation water need in Zambian condition

Table 19: Cotton irrigation water need in Zambian condition

Table 20: Peanut/Groundnut irrigation water need in Zambian condition

Table 21: Sorghum irrigation water need in Zambian condition

Table 22: Potential volume of water recharger by spreading channels in Million Cubic Meters

Table 17: Mean daily percentage (p) of annual daytime hours for different latitudes

Latitude	North	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
	South	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
60		0.15	0.20	0.26	0.32	0.38	0.41	0.40	0.34	0.38	0.22	0.17	0.13
55		0.17	0.21	0.26	0.32	0.36	0.39	0.38	0.33	0.28	0.23	0.18	0.16
50		0.19	0.23	0.27	0.31	0.34	0.36	0.35	0.32	0.28	0.24	0.20	0.18
45		0.20	0.23	0.27	0.30	0.34	0.35	0.34	0.32	0.28	0.24	0.21	0.20
40		0.22	0.24	0.27	0.30	0.32	0.34	0.33	0.31	0.28	0.25	0.22	0.21
35		0.23	0.25	0.27	0.29	0.31	0.32	0.32	0.30	0.28	0.25	0.23	0.22
30		0.24	0.25	0.27	0.29	0.31	0.32	0.31	0.30	0.28	0.26	0.24	0.23
25		0.24	0.26	0.27	0.29	0.30	0.31	0.31	0.29	0.28	0.26	0.25	0.24
20		0.25	0.26	0.27	0.28	0.29	0.30	0.30	0.29	0.28	0.26	0.25	0.25
15		0.26	0.26	0.27	0.28	0.29	0.29	0.29	0.28	0.28	0.27	0.26	0.25
10		0.26	0.27	0.27	0.28	0.28	0.29	0.29	0.28	0.28	0.27	0.26	0.26
5		0.27	0.27	0.27	0.28	0.28	0.28	0.28	0.28	0.28	0.27	0.27	0.27
0		0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27

Source: Irrigation Water Management: Irrigation Water Needs, 1986

Table 18: Sugarcane irrigation water need in Zambian condition

Sugarcane	Measures	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Average Temperature	°C	22	22	22	21	18	16	16	18	22	25	24	22
mean daily percentage of annual daytime hours		0,29	0,28	0,28	0,27	0,26	0,25	0,26	0,26	0,27	0,28	0,29	0,29
Crop evapotranspiration	mm/day	5,255	5,074	5,074	4,768	4,233	3,840	3,994	4,233	4,892	5,460	5,522	5,255
Growth stages		IV	IV	V	VI	I	II	III	III	IV	IV	IV	IV
Kc per Month		1,15	1,15	0,85	0,65	0,6	0,85	1,1	1,1	1,15	1,15	1,15	1,15
Crop water need	mm/day	6,04	5,83	4,31	3,10	2,54	3,26	4,39	4,66	5,63	6,28	6,35	6,04
Crop water need	mm/month	181,29	175,04	129,38	92,98	76,19	97,92	131,79	139,68	168,79	188,37	190,50	181,29
Rainfall of precipitation	mm/month	213	173	102	22	3	0	0	0	1	15	84	192
Effective Rainfall	mm/month	145,4	113,4	56,6	3,2	-8,2	0	0	0	0	0	42,2	128,6
Irrigation water need	mm/month	35,89	61,64	72,78	89,78	84,39	97,92	131,79	139,68	168,79	188,37	148,30	52,69

Table 19: Cotton irrigation water need in Zambian condition

Cotton	Measures	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Average Temperature	°C	22	22	22	21	18	16	16	18	22	25	24	22
mean daily percentage of annual daytime hours		0,29	0,28	0,28	0,27	0,26	0,25	0,26	0,26	0,27	0,28	0,29	0,29
Crop evapotranspiration	mm/day	5,255	5,074	5,074	4,768	4,233	3,840	3,994	4,233	4,892	5,460	5,522	5,255
Growth stages		II-III	III	III-IV	IV	IV						I	II
Kc per Month		0,88	1,15	1,09	0,75	0,38						0,45	0,75
Crop water need	mm/day	4,62	5,83	5,53	3,58	1,61	0,00	0,00	0,00	0,00	0,00	2,48	3,94
Crop water need	mm/month	138,73	175,04	165,91	107,28	48,25	0,00	0,00	0,00	0,00	0,00	74,54	118,23
Rainfall of precipitation	mm/month	213	173	102	22	3	0	0	0	1	15	84	192
Effective Rainfall	mm/month	145,4	113,4	56,6	3,2	0	0	0	0	0	0	42,2	128,6
Irrigation water need	mm/month	-6,67	61,64	109,31	104,08	48,25	0,00	0,00	0,00	0,00	0,00	32,34	-10,37

Table 20: Peanut/Groundnut irrigation water need in Zambian condition

Peanut/Groundnut	Measures	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Average Temperature	°C	22	22	22	21	18	16	16	18	22	25	24	22
mean daily percentage of annual daytime hours		0,29	0,28	0,28	0,27	0,26	0,25	0,26	0,26	0,27	0,28	0,29	0,29
Crop evapotranspiration	mm/day	5,255	5,074	5,074	4,768	4,233	3,840	3,994	4,233	4,892	5,460	5,522	5,255
Growth stages		I	II	II-III	III-IV	IV	I	II	II-III	III-IV	IV		
Kc per Month		0,45	0,75	0,95	0,99	0,47	0,45	0,75	0,95	0,99	0,47		
Crop water need	mm/day	2,36	3,81	4,82	4,72	1,99	1,73	3,00	4,02	4,84	2,57	0,00	0,00
Crop water need	mm/month	70,94	114,16	144,60	141,62	59,68	51,84	89,86	120,63	145,30	76,99	0,00	0,00
Rainfall of precipitation	mm/month	213	173	102	22	3	0	0	0	1	15	84	192
Effective Rainfall	mm/month	145,4	113,4	56,6	3,2	0	0	0	0	0	0	42,2	128,6
Irrigation water need	mm/month	-74,46	0,76	88,00	138,42	59,68	51,84	89,86	120,63	145,30	76,99	-42,20	-128,60

Table 21: Sorghum irrigation water need in Zambian condition

Average Temperature	°C	22	22	22	21	18	16	16	18	22	25	24	22
mean daily percentage of annual daytime hours		0,29	0,28	0,28	0,27	0,26	0,25	0,26	0,26	0,27	0,28	0,29	0,29
Crop evapotranspiration	mm/day	5,255	5,074	5,074	4,768	4,233	3,840	3,994	4,233	4,892	5,460	5,522	5,255
Growth stages		I-II	II-III	III-IV	IV								I
Kc per Month		0,69	0,98	1,04	0,54								0,18
Crop water need	mm/day	3,63	4,97	5,28	2,57	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,95
Crop water need	mm/month	108,77	149,16	158,30	77,24	0,00	0,00	0,00	0,00	0,00	0,00	0,00	28,38
Rainfall of precipitation	mm/month	213	173	102	22	3	0	0	0	1	15	84	192
Effective Rainfall	mm/month	145,4	113,4	56,6	3,2	0	0	0	0	0	0	42,2	128,6
Irrigation water need	mm/month	-36,63	35,76	101,70	74,04	0,00	0,00	0,00	0,00	0,00	0,00	-42,20	-100,22

Table 22: Potential volume of water recharger by spreading channels in Million Cubic Meters

Spreading channels	Total wetted perimeter for full length of spreading channel [m²]									
Material	**10 000**	**20 000**	**30 000**	**40 000**	**50 000**	**60 000**	**70 000**	**80 000**	**90 000**	**100 000**
Gravel, medium	133,9200	267,8400	401,7600	535,6800	669,6000	803,5200	937,4400	1 071,3600	1 205,2800	1 339,2000
Sand, medium	5,9520	11,9040	17,8560	23,8080	29,7600	35,7120	41,6640	47,6160	53,5680	59,5200
Dolomite	0,0005	0,0010	0,0015	0,0020	0,0025	0,0030	0,0035	0,0040	0,0045	0,0050
Clay	0,0001	0,0002	0,0003	0,0004	0,0005	0,0006	0,0007	0,0008	0,0009	0,0010
Limestone	0,4662	0,9325	1,3987	1,8650	2,3312	2,7974	3,2637	3,7299	4,1962	4,6624
Schist	0,0992	0,1984	0,2976	0,3968	0,4960	0,5952	0,6944	0,7936	0,8928	0,9920
Granite, weathered	0,6944	1,3888	2,0832	2,7776	3,4720	4,1664	4,8608	5,5552	6,2496	6,9440
Basalt	0,0050	0,0099	0,0149	0,0198	0,0248	0,0298	0,0347	0,0397	0,0446	0,0496