Water balance of the Juba and Shabelle Rivers in Ethiopia-Somalia

Mesenbet Yibeltal Sebhat

Department of Water Resources and Irrigation Management, Bahir Dar University, P.O. Box 5501
Bahir Dar, Ethiopia.

Email: mesyibseb@yahoo.com; Tel: +251913212629

Abstract

The Juba and Shabelle Rivers are the only perennial and transboundary rivers in Somalia but two-thirds of the river basins are located outside Somalia, mostly in Ethiopia, with a part of the Juba basin in Kenya. The two rivers originate from the Bale mountain ranges at an altitude of about 4230 m in the Ethiopian highlands flowing towards the Indian Ocean crossing the border between Ethiopia and Somalia. The study area was delineated using a 30 m resolution Shuttle Radar Topography Mission (SRTM) digital elevation model. To fulfill the research objectives, the rainfall and daily runoff data were collected from the FAO SWALIM project office and database, the LocClim v.1.10 database and the TRMM satellite product. The daily runoff data was stored and analyzed using the HEC-DSSVue 2.0.1 system for the basic statistical analysis and a correlation testing of TRMM data and measured rainfall data. The areal rainfall was calculated using the Thiessen polygon method with the ArcGIS software and the actual evaporation was determined using the water balance method. The Juba and Shabelle Rivers have two peak flows during the Deyr and Gu flood seasons. The Shabelle River flow is decreased at the downstream runoff stations during the two peak flow seasons but there is only a very small flow reduction in the Juba River. The annual daily peak flows were observed for the Juba River at the Luuq runoff station and for the Shabelle River at the Belet Weyne runoff station, but during the Hagaa and Jilaal seasons the daily flow for the two rivers are very low and even close to zero. The actual evapotranspiration was determined as a remaining part of the water balance equation and it is mainly depended on the rainfall in each sub basin.

Keywords: Juba River, Shabelle River, Water balance

INTRODUCTION

Somalia is located at the Horn of Africa and bordered by Ethiopia to the west, Djibouti to the northwest, the Gulf of Aden to the north, the Indian Ocean to the east and Kenya to the Southwest. Somalia’s total land area is 637,600 km², of which 45% is classified as rangelands suitable for livestock grazing, 30% is classified as desert land, 14% is covered by forest and 11% is arable land (Houghton-Carr et al., 2011). The Juba and Shabelle River basins are international river basins at the Horn of Africa drained through Ethiopia, Kenya and Somalia and the only perennial rivers flowing through Somalia.

A basin water balance assessment includes the analysis in the interactions among various types of water uses and users, and in the process, it helps in better understanding the physical, environmental, social and economic influences that impinge on the water use and management activities (Bhawan, 2001; Ufoegbune et al., 2011). These facts are clearly revealed by analyzing and comparing the specific water availability for a specify period of time for different regions. Similarly, a more comprehensive analysis requires knowing the adverse effects of a rapid degradation of the environment and other ecological problems arising from severe competition for water to be practiced between different users in riparian countries (Tadesse and Mohammed, 2009; Tafesse et al., 2010).
In a river basin water balance view, consistent issues of quantity and quality of surface water and groundwater resources can be more comprehensively analyzed (Dung, 2011; Fanta et al., 2001). The water balance of the Shabelle and Juba River basins can be determined by calculating the input, output, and storage changes of water in the basins. This water balance assessment is important for an efficient water resources use and management (Hussain, 2011; Johnson and Curtis, 1994). It can provide basic information for planning of energy production, irrigation use, water supply and prevention against floods.

Almost all the Somalia’s surface water resources exist in these rivers, whereas runoff contribution in Somalia is normally minimal or almost insignificant. The Shabelle River basin is larger in size and the Shabelle River is longer than the Juba River, but Shabelle River is low in annual runoff compared with Juba River due to climatic and geological conditions in the catchment (Basnyat, 2009). The total catchment area for the Shabelle River basin is 216,243 km$^2$ at Awdgele and for the Juba River basin 298,654 km$^2$ at Jamame.

About two-thirds of these areas are outside Somalia, mainly in Ethiopia. The two rivers originate from the Bale mountain ranges at an altitude of about 4230 m in the Ethiopian highlands flowing towards the Indian Ocean crossing the border between Somalia and Ethiopia (FAO SWALIM, 2010).

**MATERIALS AND METHODS**

**Area Description**

The Juba and Shabelle River basins are located between the longitudes 41°53’ and 46°09’ east and between the latitudes 0°16’ south and 5°04’ north inside Somalia. The area of the Juba and Shabelle Rivers basins are 218,114 km$^2$ (to Jamame, excluding Shabelle basin) and 296,972 km$^2$ (to the Juba confluence), respectively (Basnyat and Gadain, 2009).

The climate conditions for the Juba and Shabelle River basins can be described as mainly arid and semi-arid, and the climate is influenced by the north and south-easterly air flows of the Intertropical Convergence Zone (ITCZ). The north and south-easterly air masses meet at the Intertropical Front (ITF) and raise air upwards to form rain (Muchiri P.W., 2007a). Somalia has a bimodal rainfall distribution, with two rainy seasons (Gu and Deyr). The Gu season dominates over the Deyr in quantity and reliability of rainfall and as such it is treated as the primary rainy season. The Gu rains start as early as the second half of March and then increase in April all over the basins. Temperatures vary both across location and seasons. The mean annual temperatures ranging between 25°C-30°C, with a maximum temperature of 41.3°C in March and a minimum temperature of 17°C in January. In areas near the rivers the relative humidity is...
high; ranging from about 75–80%, but further inland away from the rivers the air is much drier. Relative humidity is higher in the coastal areas, where it usually exceeds 80% (FAO SWALIM, 2010). Evapotranspiration is high throughout the study area. The highest potential evapotranspiration occurs in the northern areas of Gedo, Bakool and Hiraan regions where it exceeds 2100 mm/yr; in the rest of the area it is between 1500 and 2000 mm/yr (Houghton-Carr, et al., 2011).

The geography of two river basins has been developed due to the outcropping of the metamorphic basement complex, made up of migmatite and granite. Sedimentary rocks such as limestone, sandstone, and gypsiferous limestone are present, as well as an extensive, wide system of coastal sand dunes (Paron and Vargas, 2007). The river basins are characterized by three morphologic regions. The upper region can be described as high mountains, steep slopes and rugged features, mountain peaks and high plateaus with monsoon winds and rainfall, whereas in the middle region, gentle slopes and reliefs occur and transport and deposition is dominating (FAO SWALIM, 2010). The land covers in the basins consist mostly of natural vegetation and crop fields, urban areas, dunes and bare lands, and natural water bodies. The vegetation consists of bush lands, grasslands and riparian forest. In the headwaters of the Juba and Shabelle River basins, where rainfall is generally high and losses are relatively low, surface water resources are abundant. However, in the middle sections, the rainfall becomes less frequent and decreases, losses increase and runoff is highly localized and seasonal, the rivers carry considerable volumes of water during most of the year (Basnyat, 2007). The high floods in the Juba and Shabelle Rivers both cause advantages and destructions for the people living in the riverine areas (Houghton-Carr, et al., 2011). The area of the Juba and Shabelle rivers has different hydro-geological structures for exploring groundwater in alluvial deposits and weathered basements (Paron and Vargas, 2007; and Basnyat, 2007).

**METHODOLOGY**

The general steps followed in the study of the water on the two rivers of the study area are described below:

Data screening is the primary step to process data. Collected meteorological and hydrological data can contain errors due to anthropogenic and natural factors. As a consequence before using the data, the quality of the data has to be checked and filling the missing data in time series using suitable methods is necessary (Laat, 2010). Data screening was carried out before the progress of data analysis and further use. Missing gaps were filled based on linear regression methods.

Linear regression analysis was used for data filling and completion. This method is based on finding a significant correlation between closed by or adjacent stations and fitting the best straight line through the recorded values.

\[
Y = C + C1X1 + C2X2 + C3X3 + \ldots + CnXn \tag{1.1}
\]

Where: Y is a series of values of the base station (dependent variable), Xn is a series of values of neighboring station i (independent variable), C is the equation's constant, Cn is the equation's coefficients

Meteorological parameters such as rainfall, temperature, relative humidity and potential evaporation were collected from the NewLocClim (http://www.fao.org/nr/climpag/pub/en3_051002_en.asp) and FAO SWALIM (http://www.fao.org/swalim/) database. The meteorological variables such as temperature, relative humidity and potential evaporation for the study area were collected from the NewLocClim_V1.10 (FAO) database.

Among different types of TRMM products, this study has used TRMM-3B42 data. The product is a standard 3h time step product with a spacing of 0.5 degree spatial resolution. TRMM Microwave Imager (TMI), Visible Infrared Radiometer Scanner (VIRS) and Precipitation Radar (PR) are some of the instruments used in TRMM for the estimation of rainfall (Kidd et al., 2003). TRMM can accesses all available rainfall information and the accessibility of data with the website: http://gdata1.sci.gsfc.nasa.gov/daac-bin/G3/gui.cgi?instance_id=TRMM_3-Hourly

Hydrological and statistical data analyses are necessary to check the consistency or the homogeneity of the data set (Dung, 2011). Time series analysis is used for the detection of inconsistencies or non-homogeneities in the observation series (Patra, 2008). The measured daily time series runoff data were analyzed using the HEC-DSSVue 2.0.1 software for basic statistical analysis. The basic statistical characteristics of the time series such as mean, variance, maximum and minimum values and skewness are determined. The Gumbel probability distribution method applied as estimation for the flood frequency analysis.

**HEC-DSSVue 2.0.1 Data storage**

The HEC-DSSVue 2.0.1 software was used as a database, and for the hydrologic and statistical analysis for daily and monthly river flow measurements. This program was developed by the Hydrologic Engineering Centre's (US Army Corps of Engineers) to store, calculate, plot and edit time series and paired data retrieving serial data for application and utility programs. It is a Java-based graphical user interface program for graphing, tabulating, editing and manipulating HEC-DSS river flow data (USACE-HEC-DSS, 2010).

**Flow Duration Curve**

The flow duration curve (FDC) is expressing the hydro-
logical characteristics of river flow and provides a graphical view of the variability of river flow and a cumulative distribution function of the daily flow. The flow duration curve describes the relationship between the flow and the percentage of time that the flow is equalled or exceeded (Mohamoud, 2008). It is derived by portioning the flow hydrograph, ranking the flows in descending order and sorting by the probability of a given flow being exceeded. The exceedence probability is usually expressed as the percentage of time that a flow is exceeded. Therefore, e.g. the Q95 value is the flow exceeded 95% of the time.

The slope of the flow duration curve indicates the relative flow variability (climatic or anthropogenic factors) and the amount rainfall in the basins. The FDC equation for the available time series can be formulated as:

\[ P = 100 \times \left( \frac{M}{n+1} \right) \]  
\[ (1.2) \]

Where: \( P \) = the probability indicates flow will be equalled or exceeded (% of time), \( M \) = the ranked position (dimensionless), \( n \) = the number of events for period of observe (dimensionless)

**GIS data system**

The Juba and Shabelle River basins were delineated at basins and sub-basins scale using the ArcGIS 9.3.1 software tool. A GIS database was created by the use of all available spatial information provided by the SWALIM project and other open resources. Different climatic and meteorological data sources and free available data from the SWALIM metadata source like administrative map, irrigation information, land, water and other shape files were used. These files were available from the FAO SWALIM project database (http://www.fao-swaliim.org/).

All spatial GIS input data files were projected to a Lambert Azimuthal equal-area projection system using ArcGIS 9.3.1. The Digital Elevation Model (DEM) used to delineate the Juba and Shabelle River basins was the 30m spatial resolution Shuttle Radar Topography Mission (SRTM) digital elevation model. Also raster files like slope, drainage network, flow accumulation, flow direction and sub basins processing units were available.

**Thiessen Polygon Method**

In most hydrologic analyses precipitation is the input for the basins and the average depth of precipitation over the area is computed by different methods. For this work, the estimation of the basins areal rainfall distribution is based on the Thiessen polygon method. In this method, lines were constructed using the ArcGIS tool by connecting all rainfall stations inside and near to the basins. The connecting lines are bisected perpendicularly to form a polygon around each station (Tatalovich et al., 2006). The perpendicular bisectors for each triangle edge are generated, forming the edges of the Thiessen polygons. The locations at which the bisectors polygons intersect determine the locations of the Thiessen polygon vertices.

Thiessen polygon interpolation was used with the GIS package. It is a relatively easy procedure that needs point coverage for input and is executed using the ArcGIS toolbox command (Gold, 1991). The Thiessen polygon method considers all the measuring stations in a catchment on the basis of their aerial coverage and linear variation in the precipitation between two gauge stations is assumed (Patra, 2008).

The Thiessen polygon average precipitation (\( P_{av} \)) in the basins is computed as:

\[ P_{av} = \frac{A_1P_1 + A_2P_2 + A_3P_3 + \ldots + A_nP_n}{A_1 + A_2 + A_3 + \ldots + A_n} \]  
\[ (1.3) \]

Where \( P_1, P_2, \ldots, P_n \) represents precipitation at stations 1, 2, 3,..., \( n \), \( A_1, A_2, \ldots \) \( A_n \) represents the area of gauge stations 1, 2, 3,..., \( n \) representing the corresponding polygons.

**Water balance calculation**

The water balance is defined by the general hydrologic equation, which is basically a statement of the law of conservation of mass as applied to the hydrologic cycle (Sokolov, 1974). The main inputs for a basin water balance are river flow and precipitation and the outputs will be evaporation and water abstraction (Wang et al., 2011; Wilk et al., 2006). The water balance of each sub basin depends on natural factors as its, climate, relief, geological situation, soil type and vegetation (Legesse et al., 2003). It also can be affected by human activities (Tate and Sutcliffe, 2001).

The water balance equations can be formulated for any area and period of time as:

\[ I - O = \frac{\Delta S}{\Delta t} \]  
\[ (1.4) \]

(De Laat and Savenije, 1999)

Where \( I \) = inflow per unit time (L/T), \( O \) = outflow per unit time (L/T), \( \Delta S/\Delta t \) = the change in storage within the system per unit of time (L/T)

The water balance of the basin for any time period of length \( \Delta t \), can be expressed in detail as:

\[ P + G_{in} - (Q + ET + G_{out}) = \Delta S \]  
\[ (1.5) \]

Dingman, 2002

Where: \( P \)=precipitation, \( G_{in} \)=groundwater inflow, \( Q \)=stream outflow, \( ET \)=evapotranspiration, \( G_{out} \)=groundwater outflow, \( Q_{gb} \)=groundwater outflow, \( \Delta S \)=change in storage,

**RESULTS AND DISCUSSION**

There is no rainfall data available from 1990 to 2001 in
Table 1. Correlation between measured and satellite data at Juba River Basin

<table>
<thead>
<tr>
<th></th>
<th>Bardheere</th>
<th>Kaitol</th>
<th>Mareere</th>
<th>Jamame</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TRMM</td>
<td>Ground</td>
<td>TRMM</td>
<td>Ground</td>
</tr>
<tr>
<td>Bardheere</td>
<td>1.00</td>
<td>0.74</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kaitol</td>
<td>0.96</td>
<td>0.62</td>
<td>1.00</td>
<td>0.89</td>
</tr>
<tr>
<td>Mareere</td>
<td>0.81</td>
<td>0.35</td>
<td>0.93</td>
<td>0.82</td>
</tr>
<tr>
<td>Jamame</td>
<td>0.97</td>
<td>0.71</td>
<td>0.89</td>
<td>0.90</td>
</tr>
</tbody>
</table>

Table 2. Correlation between measured and satellite data at Shabelle River Basin

<table>
<thead>
<tr>
<th></th>
<th>Bulo Burti</th>
<th>Mahadey Weyne</th>
<th>Afoigi</th>
<th>Awdgele</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TRMM</td>
<td>Ground</td>
<td>TRMM</td>
<td>Ground</td>
</tr>
<tr>
<td>Bulo Burti</td>
<td>1</td>
<td>0.93</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mahadey Weyne</td>
<td>0.99</td>
<td>0.90</td>
<td>1.00</td>
<td>0.94</td>
</tr>
<tr>
<td>Afoigi</td>
<td>1.00</td>
<td>0.92</td>
<td>0.98</td>
<td>0.93</td>
</tr>
<tr>
<td>Awdgele</td>
<td>0.99</td>
<td>0.88</td>
<td>0.99</td>
<td>0.90</td>
</tr>
</tbody>
</table>

almost all meteorological stations in Somalia. These gaps were filled using the TRMM data but the available data from TRMM are not covering all the missing rainfall data. Before using the remote sensed rainfall the data was checked with the ground available rainfall data. This was done by a correlation analysis.

Table 1 and 2 above show all sub basins in the Juba and Shabelle Rivers inside Somalia. It can be observed that the ground rainfall data have high correlations with the TRMM satellite data. In general, it is realistic to use these data to fill the rainfall gaps.

Hydrological Networks

There are four operational runoff stations and six stations with historic data available in the Juba and Shabelle River basins until 2011. Daily flows data are available for ten locations in each of the two rivers. These stations assist to analysis and characterizing the hydrology that would be needed for the design of water resources planning including flood management, irrigation infrastructure and hydropower development in the river basins.

Monthly Flows

The long-term monthly flow data are available from 1963 for ten stations in the Juba and Shabelle Rivers used for characterizing basins. The monthly flow data in the Shabelle River (Belet Weyne and Bulo Burti runoff stations) and Juba River (Luuq and Bardheere runoff stations) have long term daily flow data and functional runoff stations still to present. Both are in the upstream border to Ethiopia-Somalia and basins of the two rivers within Somalia less influenced by abstractions (irrigation and domestic demand) and diversions (hydropower development) (Basnyat (2007). Long-term monthly flow statistics are considered using data from 1963-1990 and 2001-2011 for Juba River and 2002-2011 for Shabelle River. During high flow season the two rivers flow contributes more than 15% of the total annual flow, while the dry month discharges nearly 2-5%.

Both rivers have two peak flow seasons during Deyr and Gu flood seasons. The rivers peak flow reaches in October and September on the Juba and Shabelle Rivers, respectively. These indicate that during Deyr season the peak flow attain at Shabelle River runoff
The Shabelle River has bigger catchment area than the Juba, whereas the flow in the Juba River is more than Shabelle River. This is because of the different geological formations and the higher average annual rainfall in the Ethiopian Highlands of its source contributes much runoff for the two river basins (Basnyat, 2007). The runoff contribution in Somalia is nearly negligible because the region has arid climatic condition, undefined drainage network and densities.

The long-term mean monthly and annual flows along the two rivers are presented in Table 3 and 4 below. The long-term mean annual flow at Luuq and Jamame are 185.7 and 168.1 m³/s and Belet Weyne and Awdgele are 81.1 and 44.8 m³/s at Juba and Shabelle Rivers, respectively. The mean annual flow volume at Luuq and Belet Weyne stations are 5.64 and 3.50 billion m³ (bcm) in the Juba and Shabelle Rivers, respectively.
Flow Duration Curve

Whereas at Awdgele and Jamaame the flow curves indicates flow variations within each curve of the season. The flows exceeding 50% and 90% of the time in the Juba River at Luuq station were 156.3 and 15 m³/s, respectively but in the Shabelle River at Belet Weyne station is 58.5 and 9.3 m³/s, respectively. At the first quarter, the flow curve (Jan-March) observed that the flow at each station shows low as compare to other quarters. During Jilaaal season, the flow at Awdgele station observes too low as compared to other seasons. Figure 6 and 7 indicates overview of the occurrences of annual daily peak flow. The upstream runoff stations (Luuq and Bardheere) at Juba River, and (Belet Weyne and Bula Burti) at Shabelle River shows the daily peak flow but others downstream runoff stations at both rivers have low flow. The peak flow at Luuq and Bardheere, and Belet
Figure 4. Quarterly flow duration Curves at Juba River (Luuq runoff station)

Figure 5. Quarterly flow duration Curves at Shabelle River (Awdgele runoff station)

Figure 6. Shabelle River runoff stations annual daily maximum flow
Figure 7. Juba River runoff stations annual daily maximum flow

Figure 8. Long-term annual areal rainfall in the Juba and Shabelle River sub basins

Table 5. Flood Frequency Analysis (m³/s) for Belet Weyne and Luuq runoff stations

<table>
<thead>
<tr>
<th>Station</th>
<th>Area (Km²)</th>
<th>Return periods (years)</th>
<th>2</th>
<th>5</th>
<th>10</th>
<th>25</th>
<th>50</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belet Weyne</td>
<td>193,288</td>
<td>266 352 409 481 534 587</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Luuq</td>
<td>168,599</td>
<td>829 1145 1,353 1,617 1,812 2,006</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Weyne and Bulo Burti have nearly equal daily peak flow and similar with time in occurrence.

Water balance calculations

Precipitation

The annual rainfall near to the Ethiopia-Somalia border (Luuq, Belet Weyne and Ceel Berde) is significantly low (200-260mm/yr), while the rainfall values in the downstream areas (Mareere, Jilib, Kismayo and Jamame) near to the coast are higher (400-760mm/yr). The annual rainfall in the Belet Weyne and Luuq sub basins have a small increase over actual evapotranspiration since the area includes high annual rainfall areas in Ethiopia, while Jamame, Awdgele and Afgoi sub basins have higher actual evaporation than rainfall. This additional increase in evaporation may appear from the swampy areas near to Shabelle and Juba Rivers. Bulo Burti, Mahadey Weyne, Awdgele and
Bardheere sub basins have nearly equal amount of annual actual evaporation and rainfall. This indicates that the two rivers and other water bodies have less contribution to evaporation on these sub basins. Figure 8 shows the overview of water balance for all sub basins in Juba and Shabelle Rivers.

In general, it can conclude that the role of Juba and Shabelle Rivers in all sub basins have less impact on long-term annual water balance. This may happen due to less or nearly negligible surface runoff contribution from each sub basins in Somalia and sub basins areas are so big compare to the river cross section that contribute for evaporation.

CONCLUSIONS

Juba and Shabelle Rivers have two peak flows during the Deyr and Gu flood seasons. The river peak flows occur in October and September in the Juba and Shabelle Rivers, respectively. The Shabelle River flow decreases at the downstream runoff stations during the two peak flow seasons due to anthropogenic and natural factors, but there is less flow reduction during two peak flow seasons at the Juba River. The upstream runoff stations (Luuq and Belet Weyne) at Juba and Shabelle rivers are less influenced by abstractions. These two upstream stations are important for getting actual river flow amounts from the source and planning activities such as water resource planning, estimating peak flow and develop flood warning strategies in southern Somalia. High flows from the two rivers causes floods in the lower basins due to over-topping to the plain areas in the surrounding but during the Hagaa and Jilaal seasons the two river daily flows are low and even close to zero. The Shabelle River has a bigger catchment area than the Juba River, whereas the flow in the Juba River is higher than in the Shabelle River. The long-term mean annual flow at Luuq and Jamame runoff stations were 185.7 and 168.1 m³/s and Belet Weyne and Awdgele were 81.1 and 44.8 m³/s at Juba and Shabelle Rivers, respectively. Long-term water balance in the sub basins indicates that the Juba and Shabelle Rivers have less impact on the evaporation in all sub basins. The actual evaporation mainly depends on sub basins rainfall. This is due to less or close to zero values of the surface runoff contribution from each sub basins in Somalia. The sub basins areas are large compared to the rivers cross section that contribute to evaporation. The long-term mean annual flow volume at Luuq and Belet Weyne runoff stations was 5,638 and 3,499 mcm in the Juba and Shabelle Rivers, respectively. If the existing irrigation infrastructure can be maintained along the rivers, irrigation water demand for the year 2035 will be 3% and 63% of the annual flow volume at Juba and Shabelle Rivers, respectively. However, during low flows, the irrigation water demand for the year 2035 will be 14% and 2% of annual flow volume at Juba and Shabelle Rivers, respectively.

ACKNOWLEDGEMENTS

I would like to thank the Netherlands fellowship program (Nuffic) for sponsoring my Master programme in the Netherlands.

REFERENCES
