

Water Balance Assessment in Unguja Island, Zanzibar, Tanzania

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by

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Abstract

For sustainable development of water resource management, there is much need of conducting frequent studies; this is due to the fast growing socio-economic activities, which has impact to this precious resource. However, this is not the case in Zanzibar whereby the last extensive water resource assessment studies was done in 1994. Water balance serves to be important tool for any further hydrological study. The aim of this study is estimate the water balance components of Unguja island, Zanzibar.

In fulfilling this target SWAT model was used for the first time in the island in water resource study. The 30-m resolution topography data set from ASTER GDEM was used as a basis for the construction of the model application. The DEM, soil map, land cover map and weather data were supplied to Map Window GIS interface for analytical standard technique of watershed delineation. As a result of this, 30 sub watersheds were defined.

Calibrated model simulated fairly well daily stream flow s in one of these sub watersheds for six years of simulation. The daily Nash- Sutcliffe coefficients were 0.60.

The results of model show fairly good fit between SWAT and previous study done by Halcrow. Model predicts surface runoff of 31.76%, 44% evapotranspiration and 24% total groundwater recharge for study area of 941 km². Although model show satisfactory results, much effort are needed in collecting monitoring data, especially for discharge data for streams.

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1. Introduction

1.1. Background

Water is always a scarce resource that needs to be harnessed so as to meet the growing basic demand for development activities. It is critical to social and economic development and often directly affects the behaviours of the society. Its scarcity affects almost all social and economic developments and threatens the sustainability of human development activities and the whole ecosystem around him. Addressing the water problem needs joint effort from various sector and multidisciplinary approach to manage this vital resource. For this reason water agenda has become a sensitive in many parts of the world.(Appelgren and Klohn, 1999)

In the last few decades, water issue has taken new vision not only from the experts and engineers only but also all stakeholders who articulate the claims, values and their common interests around water management issues. (Molle, 2009) This is because high level of water problems increases the frequency of claims between various stakeholders and endangers their security and even the threat on military conflict between the neighbouring countries (Hensel et al., 2006)

The fact that Zanzibar Island (Tanzania) is surrounded by sea without any neighbouring fresh water body except its groundwater reserve makes the issue more complex and sensitive. Like other small islands, this reserve in Zanzibar is nourished only by rainfall at current researched information available and therefore sustainability of these resources depends upon the nature. The availability of fresh water on small islands is frequently critical because it is dependent upon the temporal and spatial distribution of precipitation and on the storage potential above and below the ground. Thus water resources must be thoroughly investigated and their development carefully managed (Halcrow, 1994a).

However, in recent year, industrial development, urbanization, and increase in agricultural production, has led to scientific approach to water resource planning, development and management. Number of high level organizations like UN have taken initiatives to address the water issues and progressively carrying out activities on the quantity and quality of global/regional water resources, trans-boundary water resources management, mitigation of water related hazards, and water education and research in various aspect (Jayakumar et al., 2009) Among these approach and initiatives is conducting the research on the assessment of water balance to increase our understanding on the process and behavior of hydrologic cycles for better sustainable management of water resources (Merka, 2000).

Water balance assessment study enables evaluation of water resource and their change under the influence of anthropogenic activities but also it assists the forecasting of the consequences of artificial changes in the water body like lake, stream and groundwater basins. The necessity for clear understanding of hydrologic system becomes very essential because it forms the gateway for providing information for water resource managements (Ncube and Taigbenu, 2006).

1.2. Research Problems and Justification

For sustainable development of water resource management, there is much need of conducting frequent studies; this is due to the fast growing socio-economic activities, which has impact to this precious resource. However, this is not the case in Zanzibar whereby the last extensive water resource assessment studies was done in 1994. Some of the conceptual groundwater model made before by these studies seems to be not correct because large amount of information has become available for the last ten years from production borehole drilling (Halcrow, 1994). These justify the need of updating the previous studied by applying water balance assessment study which in turn serve as the starting point for any water resource study in the island (ZAWA-AfDB-UNHABITAT, 2008).

Tourism industry, land use changes, agriculture practice, and deforestation in Zanzibar have been expanding rapidly for the last decade and expected to further increase in the near future. This issue poses a crucial problem for the water resource and their impact need to be assessed. In this context, water balance assessment study will help at least to fill the gap of water resource information and forming basic planning tool for sustainable development of water resources in Zanzibar (Gossling, 2001).

1.3. Research objective

The main objective of this study is to estimate water balance components on daily basis by using modeling technique and remote sensing data in Unguja Island. The main objective is achieved by fulfilling the following specific objectives:

- To estimate various water balance components in Unguja Island (runoff, evapotranspiration and recharge) by using SWAT Model.
- To assess applicability of SWAT model in Unguja island.
- To develop different scenarios showing the impact of hydrologic components in the study area
- To calibrate the model using stream discharge measurements

1.4. Research question

In achieving the above objectives, the following research questions need to be answered:

- What are the dominant components of hydrological cycle that control the water resources in Unguja Island?
- Is SWAT model possible to be used in Small Island for prediction of water balance components?
- How accurate the model simulations are.

1.5. Outline of Thesis

Chapter two describe the literature review including hydrology of the small island like Zanzibar, impact of land use/cover to hydrologic cycle component and application of SWAT model in water resource study.

Chapter three describes previous study in the study area concerning water resources including surface water, groundwater water balance.

Chapter four describes the overview of the description of the study area including location of study area, population, climates, drainage, geology, geomorphology.

Chapter five describes about the detail of the method and procedure used in this study.

Chapter six describes the result and analysis of this research work

Chapter seven describes about the conclusion and recommendation

2. Literature Review

2.1. Hydrology and water balance of small islands

Particular physical feature of small islands always results in specific problems in water resources. This is due to the space limitation and scarcity of large fresh water bodies and relatively high population density. This implies economic and social problems that necessitate urgent approach in assessment of water resource so as to sustain life of people and their daily activities. In this sense, the water governance reforms and the provision of knowledge to communities are very important to minimize the potential threat for these areas (White et al., 2007)

Availability of fresh water in small islands is dependent upon the abundance and time distribution of rainfall and also upon storage potential above and below ground. Storage capacity depends on the presence of specific geologic and topographic features, but very limited by the impossibility to flood the small productive valley of small islands. The presence of perennial rivers is the result of exceptionally favorable quantities of precipitation and geological formation and topographic conditions.

Due to the limited storage possibility, the relationship between rainfall and water resources availability is much closer in small islands than in large islands. (Arenes and Huertas, 1986)

2.2. Impact of Land Cover and Land Use on hydrological cycle components

Availability of water resources in many parts of the world is highly variable both in time and space. This always poses to concerned regions the risk in its use. The impact is further escalated by anthropogenic activities that in turn have big influence on the quantity and quality of water resource. With the increasing demands on water resources, comprehensive knowledge of hydrological system and the factor that influence it becomes very essential. This is because it is the starting point for providing reliable information for its management. The understanding includes among others, land and water linkages because land uses decision are water use decisions. Understanding this anthropogenic activities especial land cover and land use by using modern modeling techniques like SWAT help to provide good management approach to land and water resources (Ncube and Taigbenu, 2006)

2.3. Application of SWAT model in water resource study

SWAT is a basin scale; continuous-time model that operates on the daily time step and it predicts the impact of management of water, sediment and agricultural chemicals in un-gauged watersheds. The model has been tested and proved to be efficient tool for assessing water resources and many other aspects in many part of the world (Gassman et al., 2007).

In water balance assessment study the major inputs in the model are climate data that includes daily precipitation, maximum and minimum temperature, solar radiation data, relative humidity and wind speed. Another essential input data are land use and soil properties.

Almost all hydrologic balance components are simulated in SWAT including, evapotranspiration, canopy interception of precipitation, partitioning of precipitation, snowmelt water and irrigation water between surface runoff and infiltration, redistribution of water within soil profile and return flow from shallow aquifers.

In SWAT model, simulation of hydrologic components of watershed is partitioned into two main partitions. The first partition is land phase of the hydrologic cycle that controls the amount of water entering the main channel in each sub-basin. The second partition is the routing phase of the hydrologic cycle that defines the movement of water sediments etc. through the channel network of the watershed to the outlet.

The watershed in SWAT model are subdivided in sub-watershed and this increase the efficient of the model because it enables the model to reflect differences in evapotranspiration for different crops and soil in these sub-watersheds (Neitsch et al., 2005). Based on combination of land use and soil, the sub-watersheds are further detailed into hydrological responses units (HRU). This is the fundamental unit in SWAT model by which calculation is based on (Immerzeel and Droogers, 2008).

The ambiguity and many complexes in the catchments hydrology can be solved with the use of SWAT Model by applying it to the region of interest, for instance (Ndomba et al., 2008b) recommended to customize the SWAT model in the engaged catchment in Tanzania to improve the watershed management practice in the area.

Although application of SWAT model is well popular especially in European countries, little have been published on the applicability of SWAT model in the tropical catchments particularly in East Africa and Nile basin. In Tanzanian catchments, for example, there are few research studies using SWAT model (Ndomba et al., 2008a). This study aimed at validation of SWAT model in data scarce environment in complex tropical catchments in Northeast of Tanzania. The model performed satisfactorily in this data poor areas but the authors have recommended a further validation effort to be done before the model is adopted for operational purpose.

3. Previous Studies

3.1. Some Selected studies

Considerable numbers of water resources have been done in Zanzibar. Most of these studies have much directed with the specific proposed project in certain areas of economy and no attempts have been made to quantify the overall water resources in the islands.

In early 1980's (Johnson, 1983) made extensive groundwater resources of Unguja island, this being part of a feasibility study for large-scale rice irrigation scheme. Following this report, hydrogeological map of Unguja and Pemba were published. Most of the later studies were very much based on Johnson's works.

Overviews of some of the reports are as follows:

In 1950's and 1960's Shell and BP jointly studied the surface and subsurface geology of coastal Tanzania including Unguja island. The purposes of the study were mainly petroleum search. (Kent et al., 1971) produce summarized presentation of the report with respect to surface geology and deep borehole data.

Johnson (1983) emphasized the available information of that time on hydrogeology focusing much on the feasibility on irrigation development scheme in Unguja. The published hydrogeological map of Zanzibar (Johnson, 1987) provides informative summary of this report.

(Halcrow, 1994b) conducted the study on Zanzibar Water Resources Development by which he provided additional information to Johnson's as well as hydrological studies of Zanzibar.

He compiled and collected historical data from different sources and conducting monitoring programs to estimate the available water resources of the islands and the demand upon them. Among the important points in the studies are:

- Estimation of acceptable yields for each groundwater zones.
- Assessment of demands and forecast demands up to the year 2015 for different sector of economy.
- Spatial distribution of the demands in relation to the water available in each groundwater zone and identification of the areas prone to over-exploitation.

More ever, Halcrow study focuses also on the feasibility of using surface water resource, extension of the area already available for irrigated rice production, as well as some options to meet future demand from economic sector like tourism. The study also shade light on the management measures to be taken for preservation of available water resources.

Finnida (1991) conducted the studies on Zanzibar Urban Water Supply Development Plan 1991-2015. The studies provide detailed information on the development plan for the rehabilitation and extension of the then existing Urban water supply systems for Zanzibar town and three towns of Pemba island, namely Wete, Chake Chake and Mkoani.

Much of the information related to hydrogeology in this report is extracted from hydrogeological Map of Zanzibar (Johnson, 1987). In addition to that some information regarding to surface water, groundwater resource and quality, environmental aspect, water resource management and meteorology were also discussed.

(Howard, 1994) made a review of water resource studies focusing on the groundwater resources in certain rural areas in Unguja and Pemba. The project which is named Zanzibar Rural Water Supply Project outlines the available water resources within the ZRWSP areas. The important activities done in this study are:

- Collection and review of relevant reports. Most of the information was taken from Halcrow report (Halcrow, 1994) and from personal communication from the author.
- Reconnaissance field investigation. This involved identification of all the existing water resource, determination of well depths, static water table, EC measurements and related hydrological aspects.
- Evaluation of available geophysical data. This includes some resistivity profiles done in previous studies which gave some clues about structural geology of the study areas.
- Selection of site for detailed geophysical study. This involved evaluation of preliminary data including aerial photographs, static water levels and EC which then led to selection of appropriate site for detailed geophysical investigation.

4. Description of the study area and data analysis

4.1. Location

Zanzibar is a part of United Republic of Tanzania. It is located between 5°40' and 6°30' S, about 40km east, off mainland Tanzania. Unguja and Pemba are the two major islands that make up Zanzibar. Unguja island (where the study is focused) also referred to as Zanzibar and has a surface area of 1660 km².

It emerged from the sea during the drift faulting of the coastal areas (Johnson, 1983). It is separated from the Tanzania mainland by a shallow ocean channel. Bathymetrical study shows that the channel of Unguja is characterized by rapid increase of water depths from 30-40m increasing to 700-900m toward north and south of the channel. This may suggest a transition from a continental to an oceanic regime (Shaghude and Wannas, 1998)

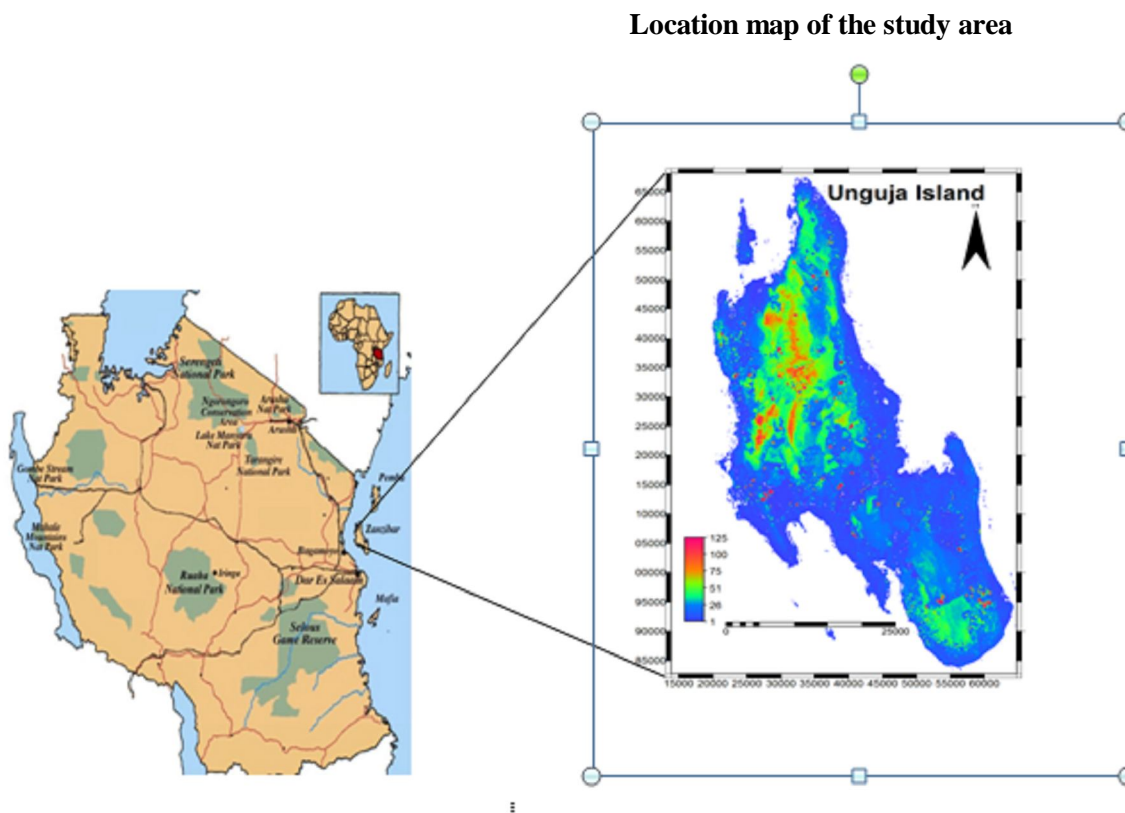


Figure 4-1 Location of the study area

4.2. Population

According to the national census that was conducted on 2002, the population of Zanzibar Island is around 981,754 with an average annual growth rate of 3.1 percent. The current population is about 1,000,000. Women constitute about 51% of the total population.

The average population density is 400 people per square kilometer. Rural population represents about 69% while urban constitute more than 30%. This situation has made Zanzibar one of the densest populated countries in Africa, South of Sahara (Tanzania Central Census Office, 2003).

4.3. Climate

In general the climate of Zanzibar Island can be categorized as tropical lowland with moderately high temperature and high relative humidity. The weather is basically determined by the position of the Inter-tropical Convergence Zone (ITCZ), which is the low pressure belt (Tierney and Russell, 2007) by which the monsoons from the northern and southern hemisphere meet. The northeast monsoon is characterized by lower wind speeds, cooler water temperatures, calmer seas and a reduced velocity (1-2 knots) of East African Coastal Current. The southeast monsoon brings high winds, warm water temperatures and rough seas with velocity of East African Coastal Current increasing to speed of 4 knots. (UNEP, 1999). This zone follows the position of the sun and in this case it passes twice a year over Zanzibar islands and consequently resulting in two major rain periods. These are:

Masika: Long rains from the south - from March to May, and
Vuli or short rains from the north - from October to December.

The average annual rainfall for the Zanzibar Island is approximately 1,600 mm, spread throughout the year and despite the distinct season they are fairly well distributed throughout hydrological year as shown in table 4.1 and figure 4.1 below. Based on the this records, it can be seen that long rain (Masika) contributes about 50% of the total rainfall while short rain (Vuli) contribute about 24% of the total rainfall in the island. This indicates that most recharge occurs during Masika rain.

Table 4-1 Average Monthly Rainfall in Unguja Island 1991 -2008

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall[mm]	73	46	184	377	260	81	53	51	45	95	146	133

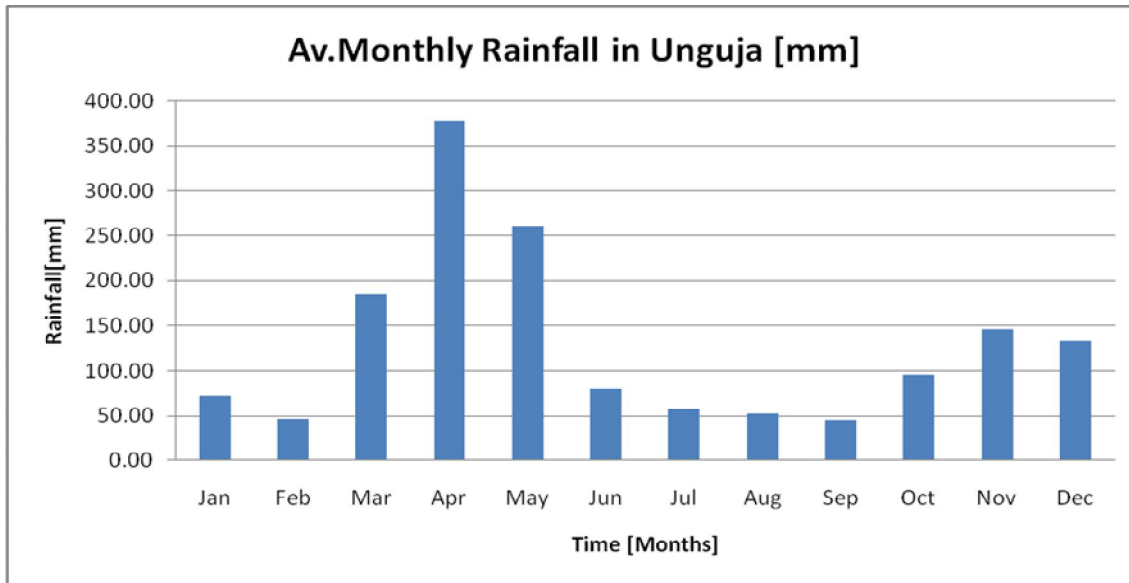


Figure 4-2 Average Monthly Rainfall in Unguja Island

Source: Data from Zanzibar Meteorological Station

Northwest parts of the island gets relatively higher rainfall compared to others while the southern part gets relatively lower. In general, spatial variability is not so high and distribution is more or less the same. This can be illustrated by two maps in Fig.4-4, and Table 4-2 below using two different approaches of interpolation. Thiessen polygons and Inverse Distance approaches which were processed by using ILWIS software to show variability of rainfall in the island.

Station	Easting	Northing	Rainfall
Kinyasini	537350	9326716	1623
Mwera	529159	9318695	1642
Selem	515493	9334583	1646
Mkwajuni	533255	9347905	1847
Kizimbani	517694	9292575	1847
Kisauni	514383	9322423	1592
Chwaka	527618	9237298	1667
Muongoni	546966	9307841	1567
Makunduc	557115	9318347	1453
Victoria	522037	9318347	1460
Tunguu	537707	9318525	1265
Mkokoton	532720	9354137	1863

Table 4-2 Spatial distribution of rainfall in Unguja island.

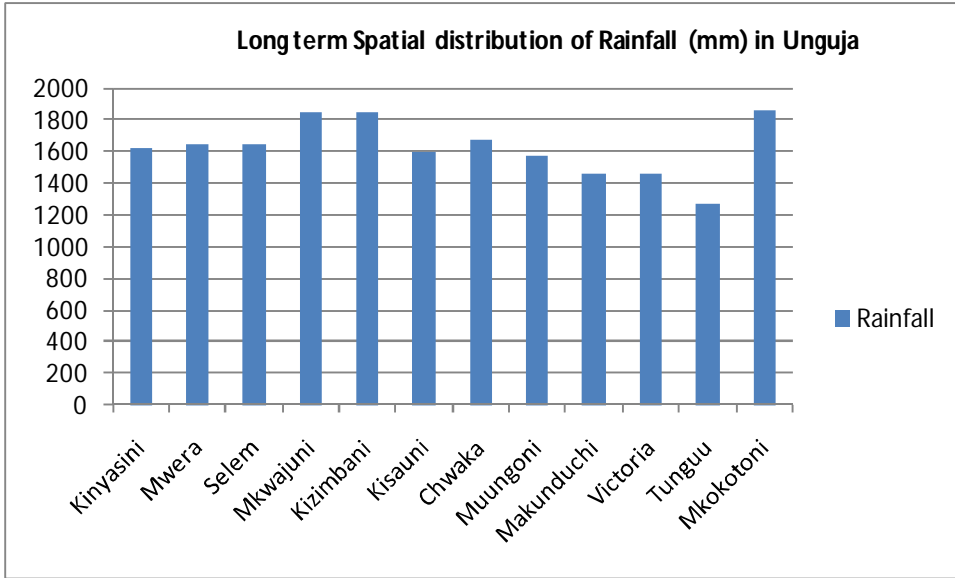


Figure 4-3 Graph showing spatial and temporal distribution of rainfall in Unguja Island.

Below are two maps showing spatial distribution of rainfall and rainfall stations in Unguja island.

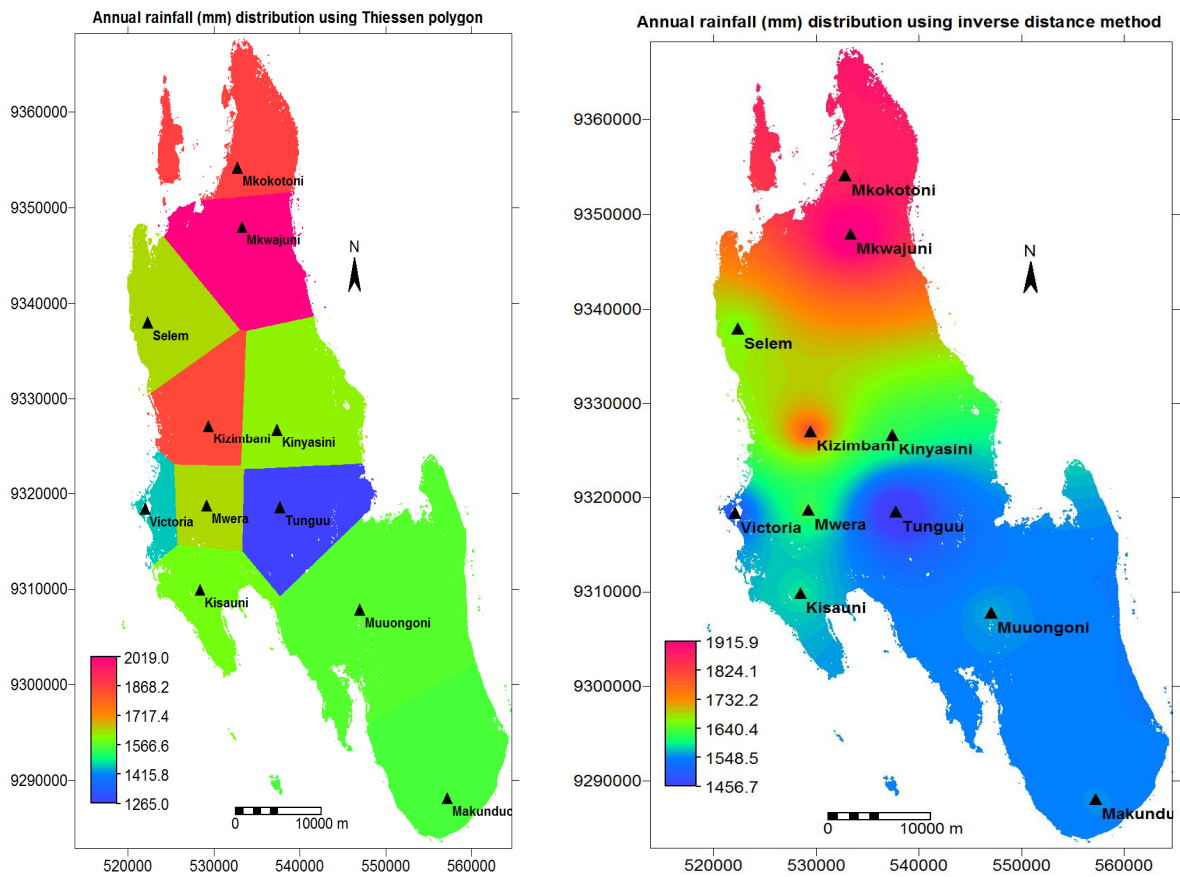


Figure 4-4 Maps showing two different approaches of rainfall interpolation.

The mean annual maximum and minimum temperature are about 30.1°C and 22°C respectively. December, January and February are the hottest months and June, July and August are the coolest ones. The table and figure below show the monthly average maximum and minimum temperature.

Table 4-3 Average Monthly Max and Min Temp in Unguja Island

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max Temp	31.53	32.14	31.65	30.11	29.38	28.44	28.12	28.47	29.04	29.86	30.96	31.09
Min Temp	23.73	24.08	23.39	23.15	21.25	21.71	20.26	19.54	19.43	20.32	21.94	23.21

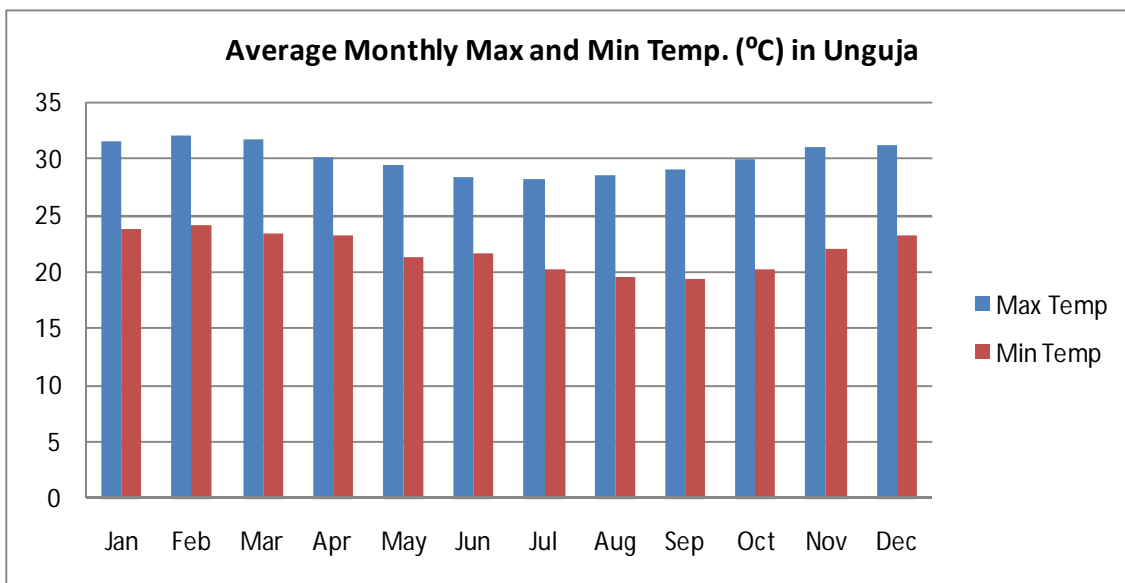


Figure 4-5 Average Monthly Max and Min Temperature in Unguja Island

Source: Data from Zanzibar Meteorological Station

Relative humidity records show the Unguja island has the mean monthly value of 68% with minimum monthly of 64% and reaches maximum of 76%. It can be seen in the figure below that in wet season the value of relative humidity is higher than the dry season.

Table 4-4 Average Monthly Relative Humidity (%)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean RH%	67	64	70	76	72	66	65	64	65	67	70	69

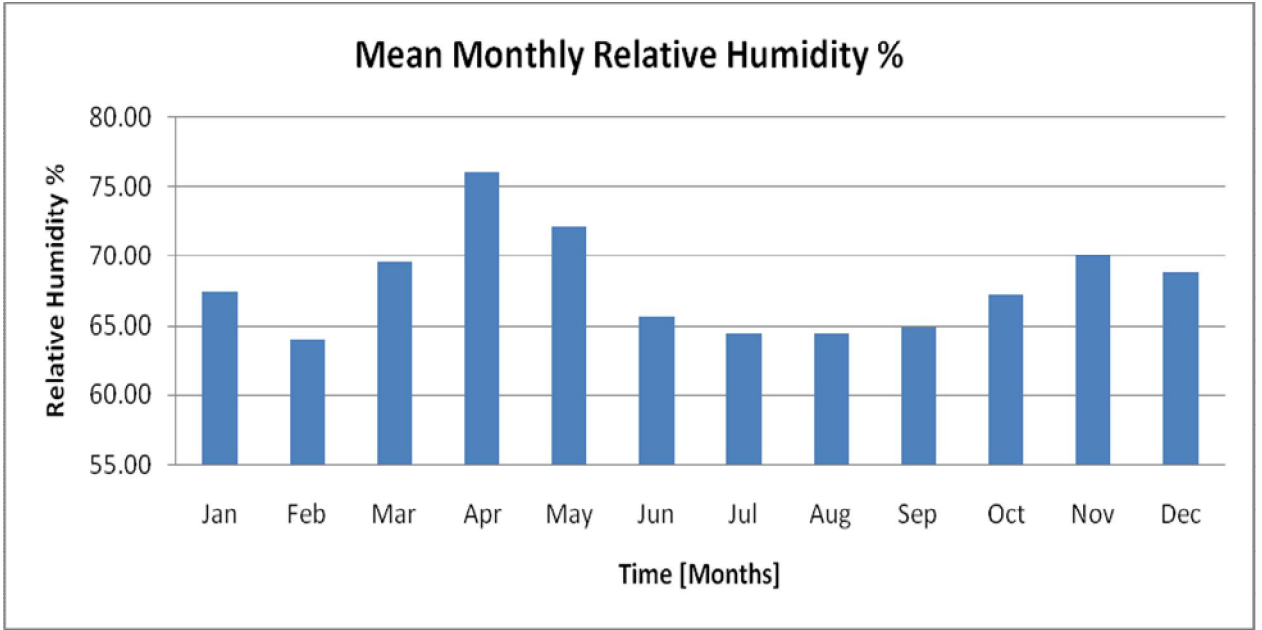


Figure 4-6 Average Monthly Relative Humidity %

Solar Radiation is the component that governs the rate of evaporation. In Unguja Island the radiation increase during the period of dry season of February and August and September with monthly values of about 20MJM⁻² while minimum value is around 16MJM⁻² in wet seasons of March – May and Nov-December.

Table 4-5 Average Solar Radiation (MJM⁻²)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Av. Mon Rad.[MJM ⁻²]	18.97	19.9	18.4	16.01	15.83	16.26	17.01	17.31	19.25	19.3	16.73	17.43

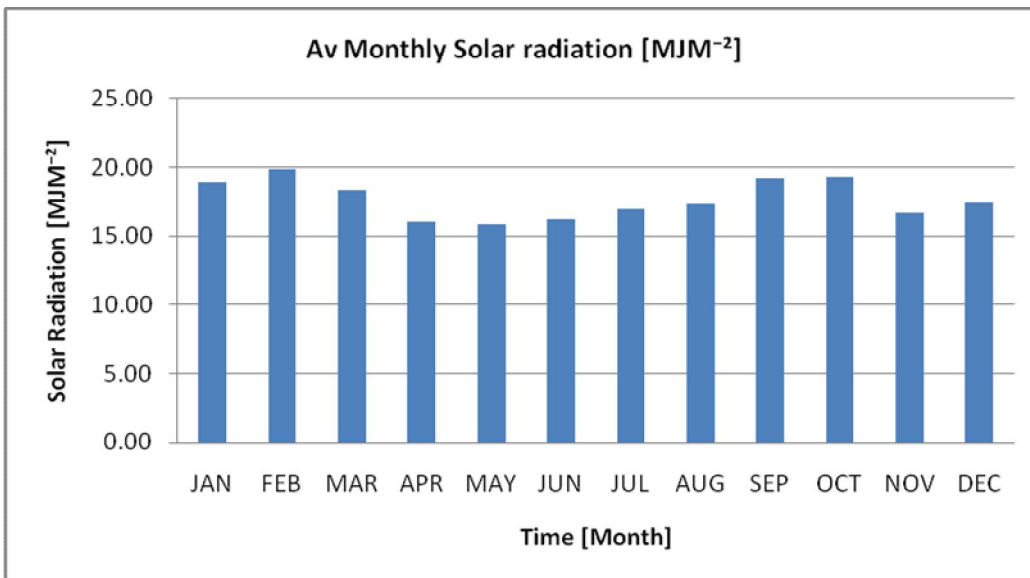


Figure 4-7 Average Solar Radiation (MJM⁻²)

Wind speed is fairly constant throughout the year in Unguja Island with monthly average of about 4m/s. The maximum speeds occur from June to September while the minimum wind speed occur during the wet season of March – May and November to December

Table 4-6 Average Monthly Wind Speed [m/s]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Av. Mon W/Speed [m/s]	3.38	3.15	2.43	2.83	3.18	3.4	4.01	3.65	3.6	3.11	2.11	2.69

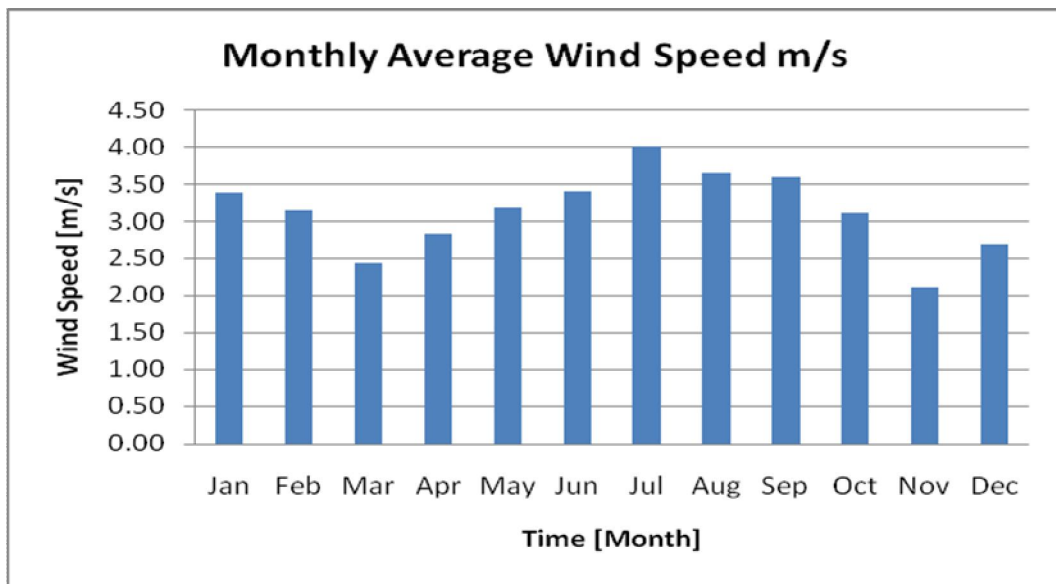


Figure 4-8 Average Monthly Wind Speed [m/s]

Meteorological data from 1991 to 2009 were used to calculate monthly evaporation as shown in the table and figure below.

The table below shows variation of monthly evaporation throughout the year.

Table 4-7 Average Monthly Evaporation [mm]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Evap. [mm]	166	157	136	99	112	122	133	135	154	154	115	119

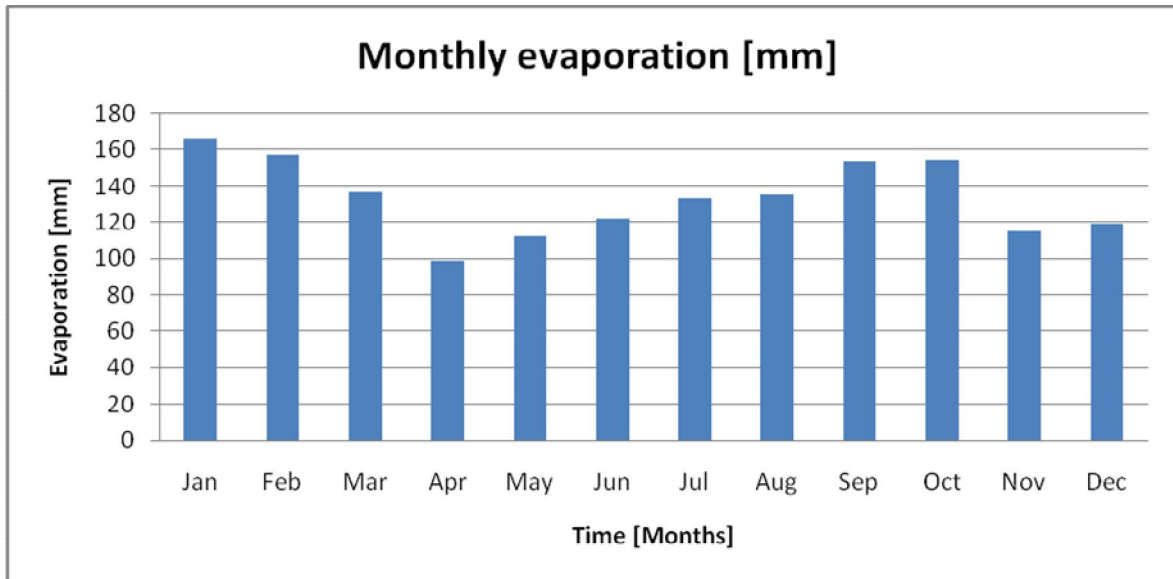


Figure 4-9 Average Monthly evaporation [mm]

It can be seen from the figures 4.7, 4.8 and 4.9 that there is somehow similar trends for solar radiation, wind speed and evaporation, which imply their relationship.

All these meteorological data were analyzed by using excel spread sheet software.

4.4. Geology

Geologically, Unguja and Pemba islands were once attached to the mainland Tanzania as part of the Rufiji River delta. Tectonic movement activities isolated these islands from the mainland. Unguja became an island a few million years ago during the Quaternary period, and is separated by shallow sea less than 100m deep.

Stratigraphy of Unguja island coincides with the one of eastern African coast with sediment layers with different compositions and increasing thickness of Cainozoic, Mesozoic and Palaeozoic eras.(Stockley, 1942)

The coastal plateau is shaped by thick sedimentary rocks, with a predominating north-south fault direction. The late tectonic development has also affected the present morphology both on land and in the sea (Shaghude and Wannas, 1995)

Its geomorphology suggests periods of higher sea level, marine erosion with wave cut cliffs and platforms, reworked marine and fluvial sediments plus tilting rocking with a raised abandoned sea cliffs and beaches, raised and submerged coastal reefs (UNDTCD, 1987)

On the surface of the Island, it can be found only Quaternary and Tertiary (Miocene) sediments. They are mainly sand, cemented sandstone and several forms of limestone like the weathered coral rock, which are mainly outcrops on most of the eastern part of the island. Thickness of the quaternary layer does not exceed 35m, but Miocene layers may go up to around 2500m. Thin quaternary deposits cover most of the Miocene soils.

Composition of these soils differs all over the island, sometime even when they date from the same geological era. This has led to several complexes of Miocene and quaternary layers with different hydrological properties (DIWI, 1990)

4.5. Drainage System.

Due to the topographic feature of Unguja island, the drainage are mainly westerly but also predominantly subsurface except in the area with heavy sticky clay soil formation. Due to presence of Karstic formation, sinkhole and caverns characteristic some of the major streams disappear into these porous formations.

This behavior of soil tends to cause infiltration being very rapid and rapid rise of water table after heavy rainfall in the areas where underlying formations are of clayey type. In some elevated areas like Donge in Northern part of the island where dissection of ridge are common, the underlying rather slowly permeable heavy clay soils caused the lateral subsurface flows which lead to sliding of top sandy layers resulting in dissected landscape and a dendrite drainage pattern (FAO, 1989)

4.6. Hydrogeology

The geology and hydrogeology of many small islands like Unguja greatly influences the type and distribution of water resources. This can be illustrated through the spatial distribution of rock and soils with varying permeability and porosity.

In Unguja, most of geological formations posses some properties, which exhibit potentials for aquifer. Most of these aquifers are unconfined although, locally can be confined. Perched aquifers are very common and often give misleading water table readings and variation in many areas.

4.7. Geomorphology

In Unguja island, geomorphology especially of coastal areas is typical related to regional style. It is resemble the one of Tanzania coast. The shore of Unguja island is characterized mainly by intertidal fringing platforms which extends to few kilometers seaward from the seashore. It should be noted that this fringing platform apart from its role in shaping the coastal area of the island, it has significant socioeconomic importance as large number of people devoted to economic activities like coconut fiber production, seaweed farming, shell fish gathering and fishing. They are also of great ecological importance as well supporting corals, turtles and wading birds and in this way they serve as prime assets for eco-tourism as well (Arthurton et al., 1999)

On the western part of Unguja flank is rather smooth and gentle. The only geomorphological exceptions are the patch reefs that disturb the smoothness shape. The geomorphological difference between the eastern and western coast of the island are suggested to be partly caused by differences in the tectonic development of the two areas. To the large extent, terrigenous input of sediments from the mainland through river Ruvu and Wami controls the sediment distribution patterns on the sea bottom in the

western part of the island. This is illustrated by the distribution of carbonate as well as the grain size parameters. The absence of any major rivers in the island means that no major transport mechanism is available for terrigenous material in the east (Shaghude and Wannas, 1998)

4.8. Soil Resources

Among the major factor determining the soil types are climate, physiographic relief, parent materials and past history (T, 1937).

Soil resources in Unguja can be grouped in three main groups. These groups are then further subdivided in other subgroups, depending on their physical and their mode of formation. According to (Hattige, 1990), these soil groups locally named as:

- (1) Kichanga Group (Sandy Group)
- (2) Kinongo Group (Loamy Group)
- (3) Kinamo Group (Clayey Group)

The groups can be summarized in the table below as follow:

Polygon No	Local name	FAO_Classif_Name	Lithological Description	Infiltration Rate	FAO Texture	Assigned Hydrologic Group
1	Shallow Kinongo	Haplic and Humic Ferralsol	Crystalline, Reef and Detrital Limestone	Medium to High	Loam	B
2	Shallow Kinongo	Haplic and Humic Ferralsol	Crystalline, Reef and Detrital Limestone	Medium to High	Loam	B
3	Shallow Kinongo	Haplic and Humic Ferralsol	Crystalline, Reef and Detrital Limestone	Medium to High	Loam	B
4	Shallow Kinongo	Haplic and Humic Ferralsol	Crystalline, Reef and Detrital Limestone	Medium to High	Loam	B
5	Shallow Kinongo	Haplic and Humic Ferralsol	Crystalline, Reef and Detrital Limestone	Medium to High	Loam	B
6	Shallow Kinongo	Haplic and Humic Ferralsol	Crystalline, Reef and Detrital Limestone	Medium to High	Loam	B
7	Shallow Kinongo	Haplic and Humic Ferralsol	Crystalline, Reef and Detrital Limestone	Medium to low	Loam	C
8	Maweni	Rhodic Ferralsol	Crystalline, Reef and Detrital Limestone	Medium to low	Loam Clay	C
9	Deep Kinongo	Rhodic Ferralsol	Crystalline, Reef and Detrital Limestone	Medium to low	Loam Clay	C
10	Deep Kinongo	Rhodic Ferralsol	Crystalline, Reef and Detrital Limestone	Medium to low	Loam Clay	C
11	Deep Kinongo	Rhodic Ferralsol	Crystalline, Reef and Detrital Limestone	Medium to high	Loam Clay	C
12	Deep Kinongo	Rhodic Ferralsol	Crystalline, Reef and Detrital Limestone	Medium to low	Loam Clay	C
13	Deep Kinongo	Rhodic Ferralsol	Crystalline, Reef and Detrital Limestone	Medium to high	Loam Clay	C
14	Kinamo	Eutric and Calcic Vertisol, cambisol	Marls, Sandy Clays and clayey sands	Low	Clay Loam	C
15	Kinamo	Eutric and Calcic Vertisol, cambisol	Marls, Sandy Clays and clayey sands	Low	Clay Loam	C
16	Uwanda	Mollic and Rendzic Leptosol	Coralline and reef limestone	high	Sandy Loam	A
17	Uwanda	Mollic and Rendzic Leptosol	Coralline and reef limestone	high	Sandy Loam	A
18	Uwanda	Mollic and Rendzic Leptosol	Coralline and reef limestone	high	Sandy Loam	A
19	Uwanda	Mollic and Rendzic Leptosol	Coralline and reef limestone	high	Sandy Loam	A
20	Uwanda	Mollic and Rendzic Leptosol	Coralline and reef limestone	high	Sandy Loam	A
21	Reddish Mchanga	Rhodic Nitisoils and Haplic Acrisols	Marls, Sandy Clays and clayey sands	Medium to high	Sandy Clay Loam	A
22	Gleyish Mchanga	Ferric and Gleyic Acrisol	Crystalline limestone, Marls, sandy and clay	Medium to high	Sandy Silt Loam	B
23	Gleyish Mchanga	Ferric and Gleyic Acrisol	Crystalline limestone, Marls, sandy and clay	Medium to high	Sandy Silt Loam	B
24	Gleyish Mchanga	Ferric and Gleyic Acrisol	Crystalline limestone, Marls, sandy and clay	Medium to high	Sandy Silt Loam	B
25	Sandy Mchanga	Dystric Cambisols and Cambic Arenosols	Marls, sandy clays and sandstone	Medium to low	Loamy Sands	B
26	Sandy Mchanga	Dystric Cambisols and Cambic Arenosols	Marls, sandy clays and sandstone	Medium to low	Loamy Sands	B
27	Maweni	Rendzic Leptosol	Sands and sandstone, marls, sand clay	High	Sandy Loam	A
28	Maweni	Rendzic Leptosol	Sands and sandstone, marls, sand clay	High	Sandy Loam	A
29	Shallow Kinongo	Haplic and Humic Ferralsol	Crystalline, reef and detrital limestone	Medium to high	Clay Loam	B
30	Shallow Kinongo	Haplic and Humic Ferralsol	Crystalline, reef and detrital limestone	Medium to high	Clay Loam	B
31	Kinamo	Eutric and Calcic Vertisol, cambisol	Marls, Sandy Clays and clayey sands	Low	Clay Loam	C

Table 4-8 Different types of soil in Unguja Island

4.9. Topography

Tectonic activities which led to the formation of deltaic feature in the coastal of Tanzania largely related to shape the surface geology of the island which then controlled much of the topography of Unguja island. Wide valley corridors, fault structures and residual hills reaching about 120m in the central region of the island characterize it. The drainage of the island is not well defined and no major rivers contribute to the overall system. But drainage channels have developed with time along the slopes of

Miocene limestone ridges, draining directly to the sea and some minor rivers drain within the corridor valleys (FINNIDA, 1991).

In general three topographic landforms can be concluded in the island, these are:

- 1) The undulating and elevated Miocene country in the central and North-western area.
- 2) The corridor or channel country
- 3) The flat coastal periphery and coral rag country.

Undulating Miocene is heavily cultivated with spices; by contrast, the country corridor with its shallow waterlogged soils remains as open grassland with local areas given over to rice production and local irrigated rice farms. On the coral rag country, which constitute over half of the island, there is virtually no soil and is dominated by sharp jagged and rocky surface which hold thickets and scraggy grasses

The prominent feature which can be found in the eastern part of the island and east coast coral rag is the multitude of elevated sea cliffs, raised strand lines and beaches, which along with the raised offshore reefs establish the nature of island movement and in particular its tilting to the west phase (Johnson, 1983)

4.10. Vegetation Cover and Land use

According to (Hettige, 1990), anthropogenic activities have greatly influenced the landscape of Unguja island in such a way that mosaic of forest re-growth, secondary forest resulting from bush fallow cultivation practices, now cover the Maweni (Coral rag) zones within the coastal and coralline areas.

Over time the landscape of Unguja has modified into a predominantly agricultural landscape. Currently cropland cover over 50000 hectares (Klein, 2008)

Due to the development of tidal and freshwater inundations, swamp specific vegetations have developed in the coastal and inland swamp areas. Most extensive swamp forests are located around central east of the island. Some of the taller species of trees attain height up to 20m and thus become suitable for timber production.

Natural forests and woodlands also occur in forest reserves, coral rag forests and mangrove and cover a total area of about 11000 hectares. Mangrove forests occur in the shallow water in coastal areas (ZILEM, 1995)

Apart from natural forest and woodland areas, there are also coral rag bush areas covered with natural vegetation especially during fallow periods. Due to growing population in these areas, deforestation tendency has become common and more shifting cultivation with shorter fallow periods. The practice of shifting cultivation involves clearing vegetation by slashing and burning it during dry season and cultivating it during wet season (Kombo and Kitwana, 1997)

4.11. Water Resource in Unguja Island

In most oceanic island like Unguja, freshwater is always limited resource. Fortunately for Unguja Island, due to high amount of annual rainfall. For the purpose of this study, water resources can be mainly categorized into two types. These are surface and groundwater resource.

4.11.1. Surface Water Resource

Topography has very important significance on the availability of surface water. On Unguja, due to its flatness feature there are few rivers. These rivers are divided into those that reach the sea or rather called coastal rivers and those that do not reach the sea, or inland rivers.

Coastal rivers are located at the northwest of the island, these are smaller rivers which do not represent significant resources. Inland rivers are mainly situated central part of the island, these rivers disappear on the coral rag limestone into the sink holes. These include River Pangeni, Mwera and Kinyasini. They are considered to have some resource value due to the contribution of their flow to the groundwater recharge. Appendix (A) show the location of the river.

Apart from these rivers, Unguja island has considerable number of springs. Among the very important ones are Bububu and Mtoni springs by which Zanzibar Town had its first supply from them.

According to (DIWI, 1990) another two springs also worth mentioned, these are Kiwani bay in the North West and Kombeni in the south of the island. It is considered that the Kombeni spring is the emergence of Mwera River, but further studies are needed to justify this. One important thing to note here is that despite the presence of springs in the southern areas, saline water intrusion was reported inland far away from this spring. This may suggests that the spring flow may be fracture controlled within the limestone formation, which operates independently, as a separate discharge mechanism. Some of the rivers and their flow discharges are shown in the table below.

River	Record Length	Av. Daily Flow	Estimated Yield	Period Rainfall	Runoff Potential
Bububu	29 Apr to 8 June	0.2 m ³ /s	700MI	571mm	30 to 40%
ZingweZingwe	31 Mar to 9 Jun	1.6m ³ /s	9800MI	933mm	30 to 50%
Kitope	30 Mar to 9 Jun	0.4m ³ /s	2600MI	938mm	40 to 55%
Mchanga	30 Mar to 8 Jun	0.4m ³ /s	2300MI	938mm	30 to 40%
Mwanakombo	24 Apr to 8 Jun	1.7m ³ /s	6700MI	670mm	40 to 55%
Kinyasini	30 Mar to 12 Jun	0.7m ³ /s	5400MI	880mm	45 to 60%
Mwera	25 Apr to 7 Jun	5.7m ³ /s	20300MI	736mm	40 to 50%
Kipange	22 Apr to 12 May	1.6m ³ /s	3000MI	448mm	40 to 50%

Table 4-9 Estimation of river discharge in Unguja Island.

Source: Halcrow, 1994.

4.12. Groundwater Resource in Unguja

In many small islands like Unguja, groundwater is the primary source of water. Assessment and evaluation of this resource needs the understanding of its aquifers potential. Unguja, being oceanic

island possesses its groundwater resources in terms of lens, which float above deeper saline aquifer. It is very crucial to maintain the balance of fresh and saline water in order to prevent rising of seawater inland.

In his study on water resource in Unguja island, (Halcrow, 1994) examined the hydrological processes and estimates groundwater recharge and subsurface flows to the sea. He delineated nine water resource zones based on their storativities. The table below shows the water resources recharge zone in Unguja.

Resource Zone	Recharge Mm ³ /yr
1	23.99
2	68.53
3	72.4
4	59.64
5	19.13
6	35.27
7	130
8	36.75
9	143
Total	564.73

Table 4-10 Recharge for water resource zone in Unguja.

4.13. Water Balance in Unguja

The water balance is an accounting of the inputs and outputs of water. It essentially relates the flows of water into the environment to the flow of water out of this environment. The water balance of such an environment whether it is an agricultural field, watershed, or continent, can be determined by calculating the input, output and storage changes of water. In most cases the major input of water is from precipitation and output is evapotranspiration. (Ritter, 2006) Mathematically, water balance can be represented as:

$$I(t) - O(t) = dS/dt \quad \dots\dots\dots 4.1$$

Where I is inflow in m³/day, O is Outflow in m³/day and *dS/dt* is rate of change in storage over a finite time step in m³/day.

Unguja island being oceanic island the water balance expression can be expressed as:

$$P = E + T + Qf + Qs + dS \quad \dots\dots\dots 4.2$$

Where : P is Precipitation, E is evaporation, T is the transpiration, Qf is the groundwater flow to the sea, Qs is the surface runoff to the sea and *dS* is the change in storage.

The above equation could be expressed in the case of Unguja island as that precipitation is the inflow to the system, while outflows are evaporation, transpiration through vegetations, surface flow to the sea

and human abstraction. During the course of long time duration, the change of groundwater storage may be neglected.

Following the previous study by (Halcrow, 1994), the water balance of Unguja can be represented by the below schematic diagram.

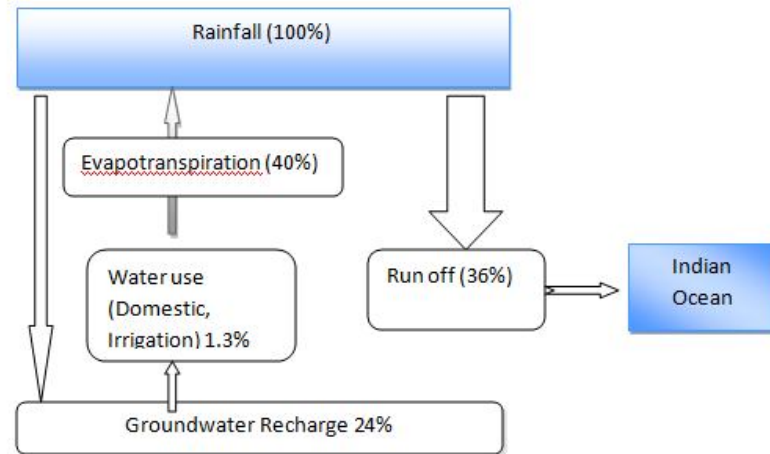
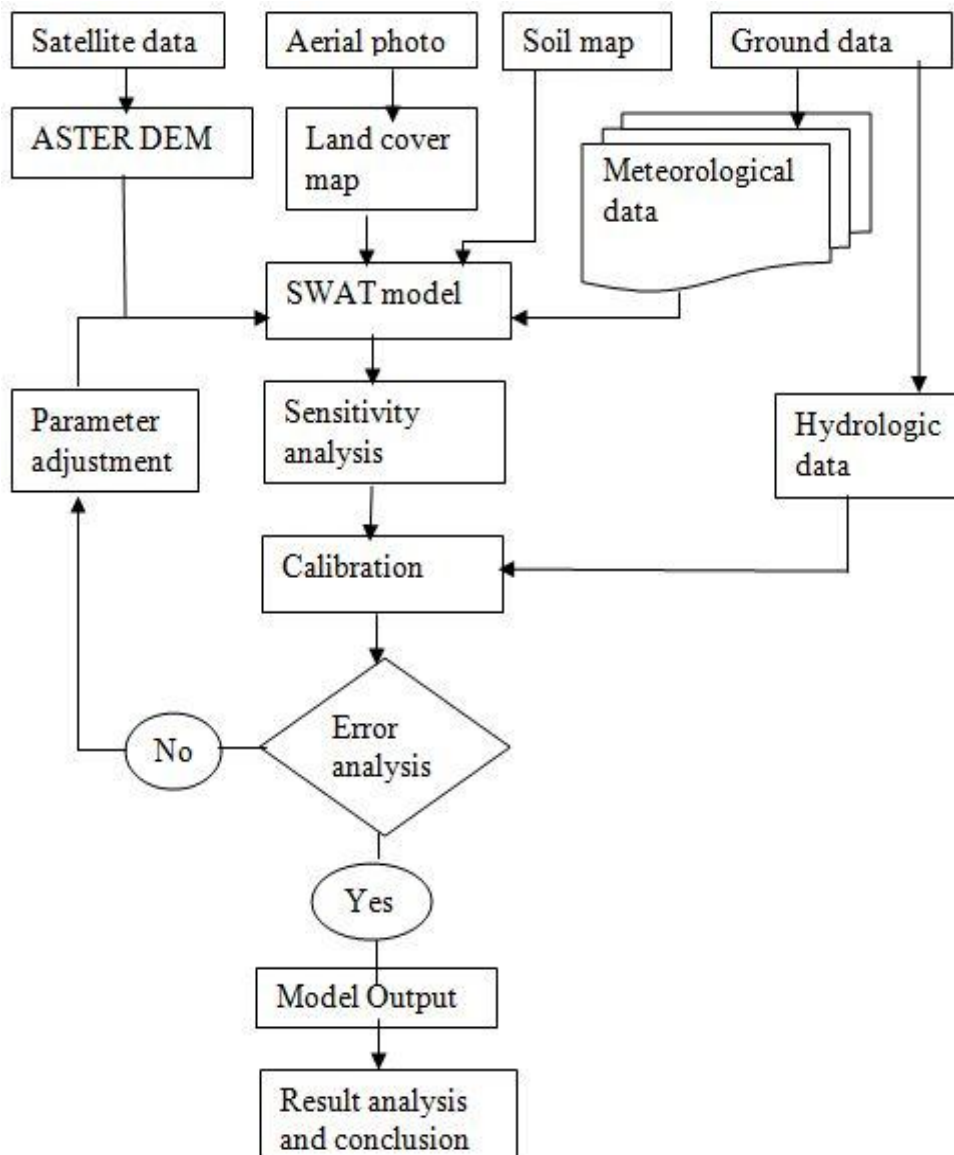


Figure 4-10 Schematic water balance of Unguja Island

Source: (Halcrow, 1994)

5. Methods and Procedure

5.1. Flow Chart.



5.2. Data Set Used

The 30-m resolution topography data set from ASTER GDEM was used as a basis for the construction of the model application. The GIS layer representing landuse/cover in the basin was based on the an interpretation of aerial photographs from 2004-2005, this was combined with information taken from Department of Land in Zanzibar and extensive field survey done during the field work. Soil map was aquired from the department of agriculture in the hardcopy and then digitized and re-classified according to SWAT model requirements. The reclassification of soil data was achieved by comparing the soil polygons with the surveyed soil/ hydrogeological map of Zanzibar to give geological description and hydrological group of the soil. This hydrological soil group in conjunction with land use/cover type were used as the basis for estimation of CN number, which is very essential to determine the amount of water that will infiltrate the soil. This may suggest that for the hydrological modelling using CN, this parameter could be the most sensitive one to the model which then evaluate the fit to river flows.

5.2.1. Meteorological and hydrological data sets.

The data sets for weather were obtained from Zanzibar Airport Meteorological Station(Kisauni) and Kizimbani Agromet Station (see fig. 4-4). For Kizimbani Station, the data consist of an 19-year series (1991 -2009) of daily precipitation, temperature, Pan evaporation, wind speed, relative humidity, dew point temperature and 3-year series (2006-2008) from Zanzibar Airport Meteorological Station. (See Appendixes) These data were originally collected in hard copy and then preprocessed in Excel spreadsheet in daily basis according to SWAT format for the input of the SWAT model which needs weather data in daily or subdaily.

The missing weather data were filled by using weather generator in-build mechanism in Map Window GIS interface software. 12 years of climatic data were used for calculation of parameters required for weather generator file as illustrated in the table below.

Table 5-1 Parameter required for weather generator file

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maxtemp (°C)	31.53	32.14	31.65	30.11	29.38	28.44	28.12	28.47	29.04	29.86	30.96	31.09
Min temp (°C)	23.73	24.08	23.39	23.15	21.25	21.71	20.26	19.54	19.43	20.32	21.94	23.21
Temp Stdev.max(°C)	0.65	0.60	0.62	1.01	0.56	0.40	0.36	0.57	0.56	0.55	2.36	0.47
Temp Stdev.min(°C)	0.64	1.86	0.80	0.73	0.40	1.82	0.66	0.75	0.73	1.11	0.59	0.58
Av.Mon precipitation (mm)	99.62	56.21	202.81	414.16	324.05	92.51	73.66	61.29	59.92	115.66	175.94	179.92
StdDaily rain (mm)	9.59	7.42	13.19	22.03	26.95	10.26	7.04	6.10	4.91	12.56	11.78	13.22
SkewDaily rain	4.31	4.68	2.94	3.09	10.63	5.90	5.44	6.66	5.95	7.26	2.73	3.51
PWD	0.17	0.16	0.53	0.95	0.44	0.24	0.37	0.38	0.43	0.37	0.44	0.29
PWW	0.41	0.24	0.49	0.65	0.69	0.38	0.32	0.34	0.36	0.36	0.45	0.49
dwet,i	7.17	4.92	15.75	21.75	18.17	8.25	10.83	11.17	11.92	11.33	13.25	11.33
0.5hrs max (mm)	84.80	54.30	84.40	167.20	428.00	96.00	66.50	70.20	59.50	140.60	72.00	112.50
Av.daily sol.rad (MJM ⁻²)	18.97	19.90	18.40	16.01	15.83	16.26	17.01	17.31	19.25	19.30	16.73	17.43
Av.daily dewpt (°C)	22.96	22.95	24.78	24.24	22.72	21.21	20.01	20.16	20.98	21.68	23.47	23.73
Av.daily wind speed (m/s)	1.97	1.85	1.26	1.30	1.35	1.52	1.51	1.31	1.21	1.14	1.08	1.50

They were then imputed in Map Window GIS interface database for simulation of watershed hydrologic parameters. Additionally, daily flow data of year 2000 -2005 from gauging station were obtained from Zanzibar Water Authority. These data were used for calibrating the model.

5.3. Model Set Up

One of the first steps in the set-up of a SWAT model application for new study area consists of identification and limitation of hydrological response units (HRUs). For this purpose, subbasin stream net work was extracted from the digital elevation data (DEM) using geo-hydroprocessing procedure in ILWIS software. This was then applied in MapWindow GIS interface for analytical standard technique of automatic watershed delineation. 10km² was used as threshold value for defining watershed minimum value. Soil, land cover maps and weather data were accessed through MWindow GIS interface with soil parameters attribute tables linked. Intermediate point for catchment slope of 10% were assigned to divide HRUs into those with average slopes for 0-10% and those with average slopes in the range 10% to the top limit. As a result 30 subwatersheds were defined, and by taking account for differences in soils, land use, and slope, the model gave rise to 30 HRUs after assigning dominance percentage approach for land use, soil type and slope. These catchments make the total area of 941km². The figure below shows the study area with number of catchments.

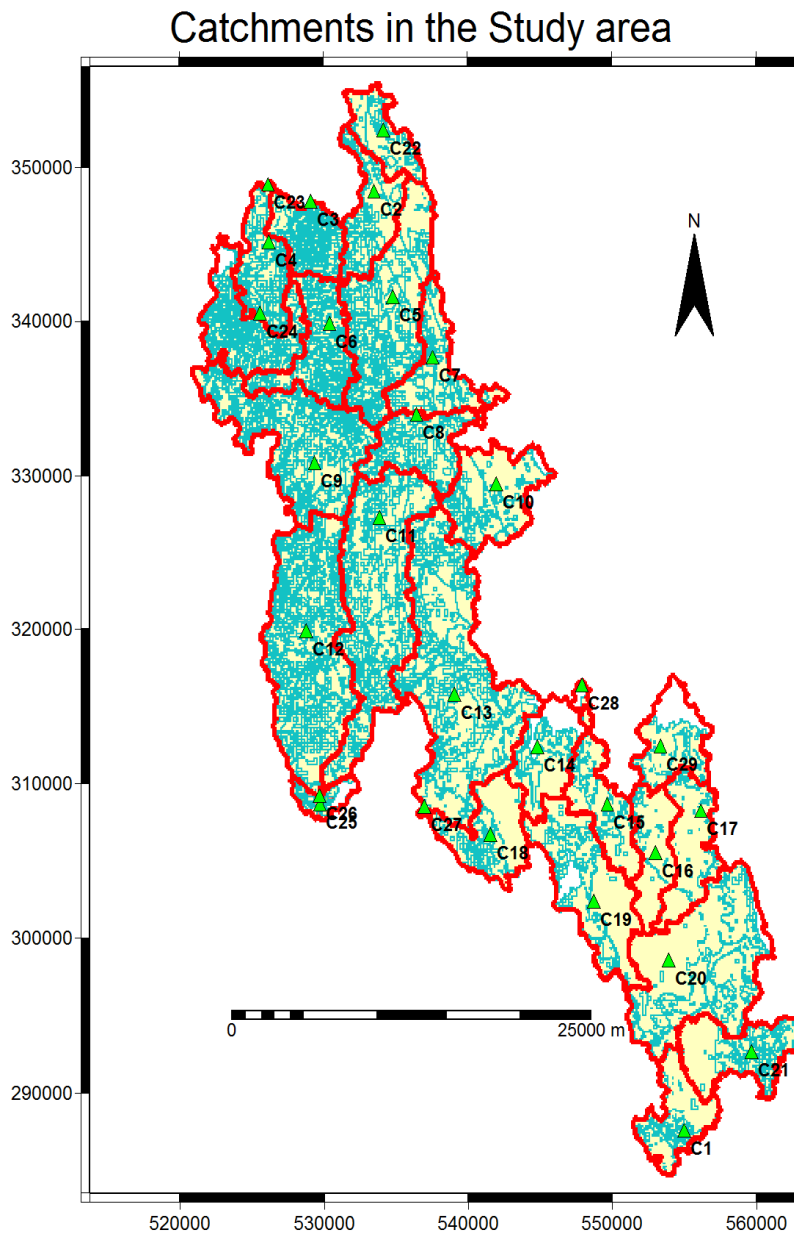


Figure 5-1 Location of Catchments in the study area

5.3.1. Land use and Soil type.

Due to the absence of locally established values for SWAT model parameter such as (CN, LAI etc.) that describe the hydrological characteristics of different land use type, some of the locally observed land use was associated with a land use type contained in the SWAT model database, see (table 5-2 and figure 5-2). As first approximation, the original parameter values corresponding to the SWAT database were used in the model. The most important type of land use/cover in the subbasin corresponds to the Shrub covering a 49.1 % followed by mixed vegetation covering about 19 %.

As for soil, it was classified according to FAO classification with large percentage being sandy loams, fig. 5-3.

Table 5-2 Unguja land use classes matched with SWAT land use and Code

Land Use Class	SWAT Land Use Class	SWATCODE	% Watershed
Agriculture	Agricultural Land-Generic	AGRL	12.0
Coastal Sand	Urban Low Resident	URLD	0.1
Forest	Forest-Mixed	FRST	0.7
Recreation Park	Grassland	GRAS	0.0
Paved Road	Transportation	UTRN	6.2
Mixed Vegetation	Mixed Grassland	MIGS	18.9
Settlement	Urban	URBN	5.9
Mixed Shrub	Shrub	SHRB	49.1
Mangrove	Wetland-Mixed	WETL	2.8
Water body	Water Body	WATB	0.1
Plantation	Cropland/Woodland	CRWO	2.1
Quarry	Commercial	UCOM	0.0
Stream	Water	WATR	1.2
Unpaved Road	Baren or Sparsly Vegetated	BSVG	0.8

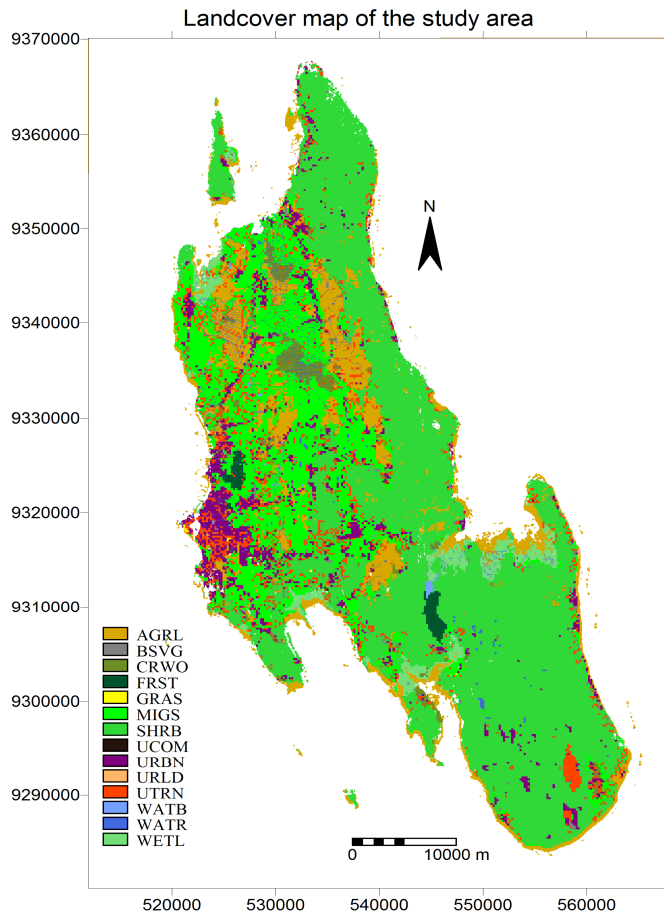


Figure 5-2 Landcover/use for the study area

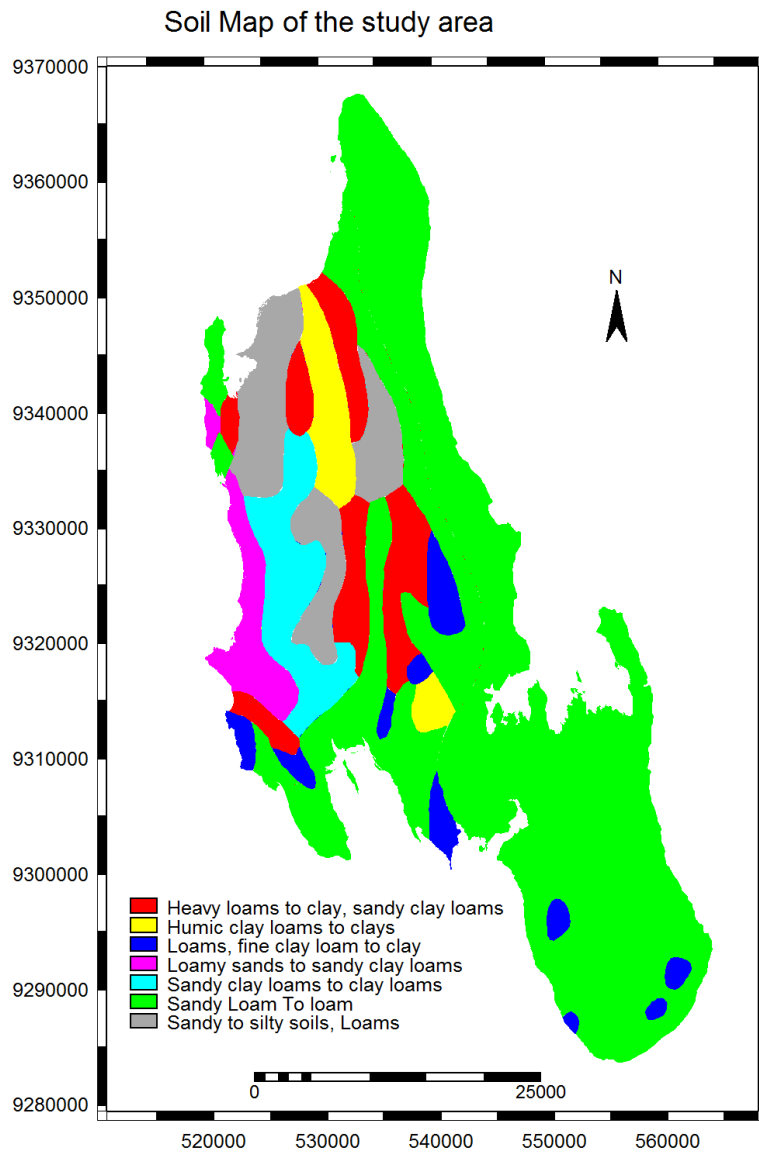


Figure 5-3 Soil map of the study area

5.4. Model Execution

After setting up step, the model was run for five year 2000-2005. In correspondence to the available input data the SCS CN approach and The Penman-Montheith method were used for calculation of runoff and potential evapo-transpiration respectively. As for rainfall, skewed normal distribution method was used. Missing weather data were filled by using the built-in weather generator.

5.5. Sensitivities Analysis and Calibration

Before calibration process, a sensitivity analysis, which is the technique to identify the response of the parameter by ranking the most sensitive parameter to the model, was done by means of LH-OAT analysis (Latin Hypercube Sampling – One at A Time, incorporated in SWAT Editor. Based on these results, a manual calibration was done, which was followed by automated calibration analysis procedure implemented in SWAT called PARASOL (Parameter Solution Method), this was applied for the most six sensitive model parameters, using the sum of the squares of the residuals (SSQ) to obtain the optimum solution.

The analysis shows ranks of parameters starting with the most sensitive to least sensitive as illustrated in the table 5-3 below. The hierarchy of sensitive parameters was then used for the auto calibration. The parameters taken in autocalibration were: were CN2, Surlag, Sol_K, Sol_Z, Sol_AWC and ESCO

Table 5-3 Sensitivities analysis results

Rank	1	2	3	4	5	6	7	8	9
Parameter	CN2	Surlag	Sol_K	Sol_Z	Sol_AWC	ESCO	Carmx	Blai	Ch_K2
Rank	10	11	13	14	15	27	27	27	27
Parameter	Slope	Alpha_Bf	Ssubbasin	Epcn	Sol_Alb	CH_N2	GW_delay	GW_Reva	Revapmn

The rank shows the order of decreasing sensitivities of the parameters and the parameters in rank 12 and ranks 16 – 26 were omitted in the above table since they pertain to water quality and tillage in agricultural activities.

In ranking sensitivities of the parameter, bounding limit for the parameter to vary has an influence, as a matter of making these scenarios, four parameters were tested in different bounding limits and the results are illustrated below.

Figure 5-4 Scenerio one showing the sensitivity of the parameter

Parameter	Lower bound	Higher bound
CN	-25.0%	25%
Alpha_Base flow	0	1
Sok_K	-25%	25%
Sol_Z	-25%	25%
Result of sensitivities		
Parameter	Rank	
Alpha_Base flow	1	
Sol_Z	2	
CN	3	
Sol_K	4	

Figure 5-5 Scenerio two showing the sensitivity of the parameter

Parameter	Lower bound	Higher bound
CN	0	25%
Alpha_Base flow	0	25%
Sok_K	0	25%
Sol_Z	0.5	1%
Result of Sensitivities		
Parameter	Rank	
Sol_	1	
CN	2	
Sol_	3	
Alpha_Base Flow	4	

6. Results and Analysis

The annually and monthly simulations of the model are presented in the tables below.

Prec (mm)	Surf. RunOff (mm)	Actual ET (mm)	PET (mm)	GW Shallow (mm)	Deep AQ RCHG (mm)	Total Recharge (mm)	Percolation (mm)	Revap (mm)	Trans. Loss (mm)	Water Yield (mm)	LatQ (mm)
1808.2	576.14	797.43	1487	244.34	21.5	249.96	430.9	127.94	4.23	829.32	8.06

Table 6-1 Annually simulation of the SWAT model for the study area

The model shows the actual evaporation and surface are among the important influential parameter which dominate the water balance of Unguja island. They altogether make more than 70% of the total annual rainfall.

	Rain	Sur. Runoff (mm)	Lat. Q (mm)	WATER YIELD (mm)	ET (mm)	PET (mm)
Jan	0.75	0.51	0.54	19.29	41.3	119
Feb	56	8.62	0.24	25.49	28.7	147
Mar	173	31.04	0.51	48.71	90.5	131
Apr	400	159.47	1.16	117.7	98.6	105
May	393.6	207.31	1.48	229.52	91.2	102
Jun	75.5	10.18	0.89	33	62.9	107
Jul	83.66	15.49	0.54	38.6	61.7	114
Aug	65.7	11.25	0.35	33.82	57	115
Sep	75.28	11.05	0.34	32.42	66.4	126
Oct	53.53	5.46	0.26	26.96	55.5	125
Nov	228.6	60.24	0.62	80.63	66.8	101
Dec	203.25	55.75	1.14	78.7	71.6	115.9

As for monthly simulation, the model show good correlation between rainfall and surface runoff whereby high amount of surface runoff occur during two wet season, in March to June and in November to December as illustrated in the figure below.

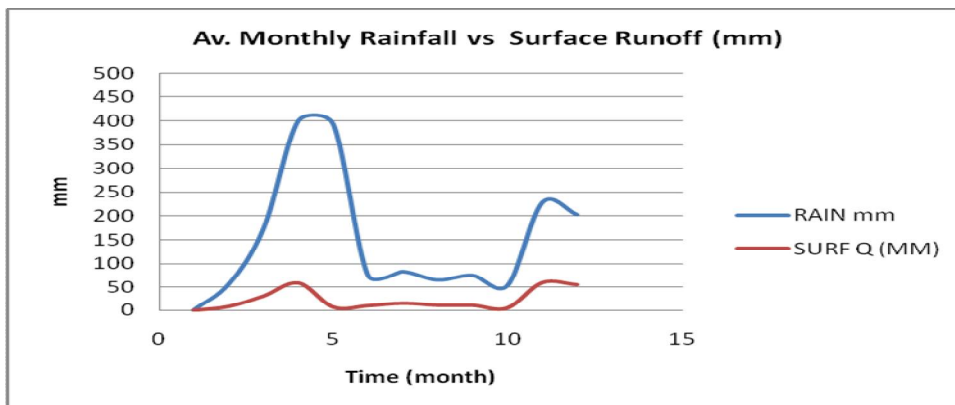


Figure 6-1 Relationship between rainfall and surface runoff

Before calibration, the model showed bad correlation and Model Evaluation Coefficient Nash-Sutcliffe and correlation coefficient were: -0.4 and 0.5 respectively this result indicate bad performance of the model simulation. In most case, the model gave overestimation results as can be seen in the fig. 6-2

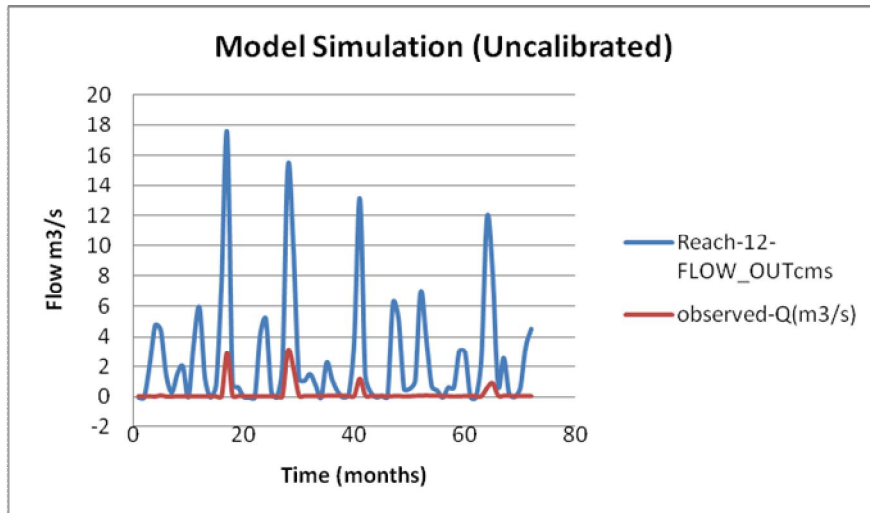


Table 6-2 Model simulation before calibration

After calibration, the model simulation was improved in such a way that Nash-Sutcliffe Coefficient was 0.602 and correlation coefficient were 0.75 respectively which is satisfactorily good and acceptable. The model still showed some overestimation for peak flow in first year of simulation but tends to slightly underestimate in the following years as shown in the figure 6-3 below.

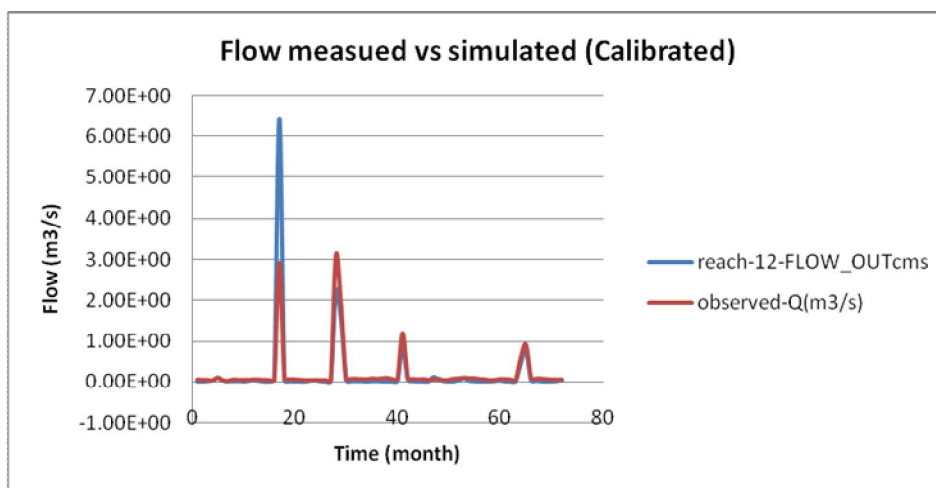


Table 6-3 Model Simulation after calibration

	Nash-Sutcliffe Coefficient	Correlation Coefficient
Before Calibration	-0.4	0.5
After Calibration	0.6	0.75

Table 6-4 Model performance values before and after calibration

The main water balance components were estimated by the model for each individual catchment as shown in the table 6-4 below. The model simulation with respect to Surface Runoff, Actual evapotranspiration and Groundwater recharge shows good fit with the previous study of water balance in Unguja by (Halcow, 1994).

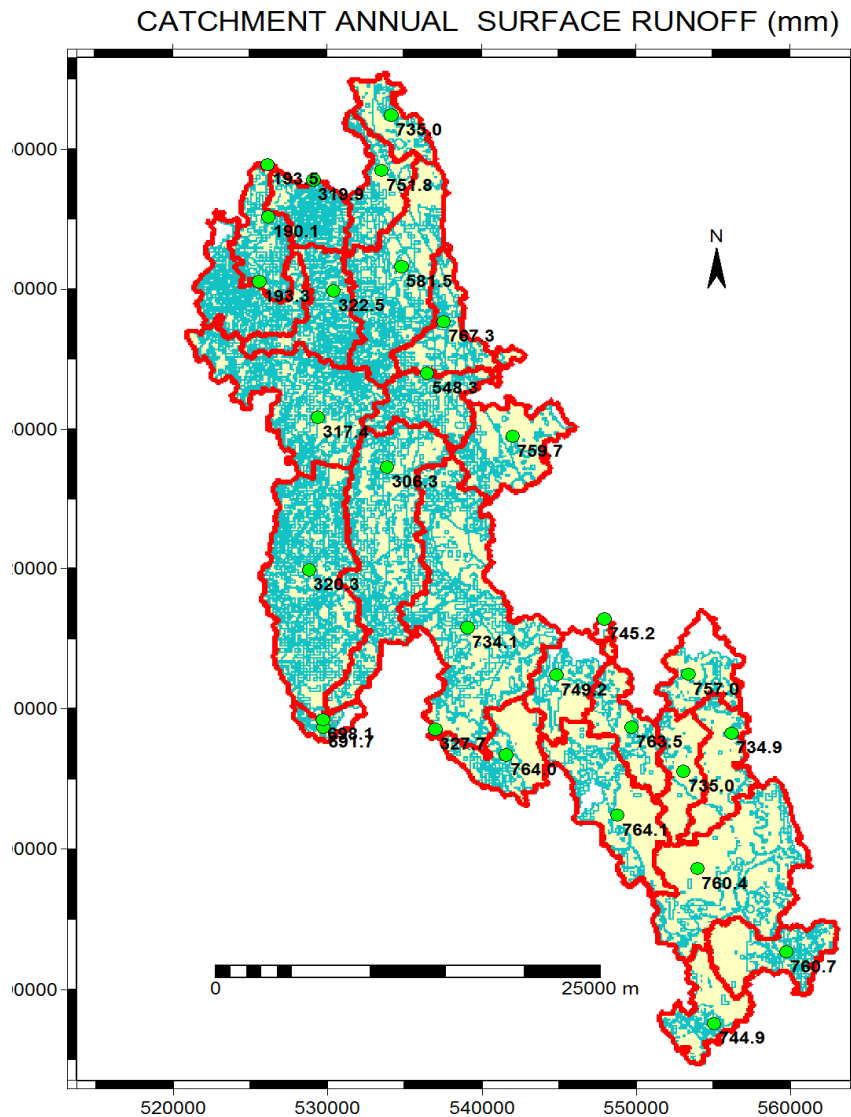
Subbasin	PRECmm	SURQmm	ETmm	GW_RCHGmm
1	1808.2	744.86	711.76	346.184
2	1808.2	751.76	708.24	333.969
3	1808.2	319.87	891.18	576.599
4	1808.2	190.08	892.64	710.684
5	1808.2	581.45	857.9	365.916
6	1808.2	322.52	903.85	560.497
7	1808.2	767.32	815.19	216.184
8	1808.2	548.31	776.43	467.082
9	1808.2	317.36	854	618.729
10	1808.2	759.72	775.87	267.476
11	1808.2	306.33	819.52	673.246
12	1808.2	320.33	840.49	634.52
13	1808.2	734.14	711.02	351.031
14	1808.2	749.18	762.94	289.193
15	1808.2	763.48	817.06	226.549
16	1808.2	735.01	712.29	356.248
17	1808.2	734.85	712	355.896
18	1808.2	764.03	816.92	221.313
19	1808.2	764.12	817.29	222.352
20	1808.2	760.4	710.17	328.093
21	1808.2	760.66	710.14	327.314
22	1808.2	734.99	710.5	342.803
23	1808.2	193.48	893.49	709.824
24	1808.2	193.28	893.34	703.049
25	1808.2	691.67	712.98	391.687
26	1808.2	698.08	807.95	296.807
27	1808.2	327.65	920.08	548.852
28	1808.2	745.19	712.26	346.636
29	1808.2	756.97	761.81	285.126
30	1808.2	193.46	893.49	717.593
Average	1808.2	574.35	797.43	426.382

Table 6-5 Average annually Catchment Water balance value

The overall average annual values for surface runoff, actual evapotranspiration and groundwater recharge are: 574.35mm, 797.43, and 426.38mm respectively which represents 23.6% for recharge, 32% for Surface runoff and 44% for evapotranspiration. This good correlation with the previous study may suggest good model prediction for hydrological components in the study area. The table below shows the comparison between SWAT prediction and Halcrow,1994 estimation for water balance components.

	ET(mm)	SURQ(mm)	GWRCHG(mm)
SWAT model	44.10%	31.76%	23.60%
Halcrow	40%	36%	24%

Table 6-6 Comparison of SWAT model and Halcrow, 1994



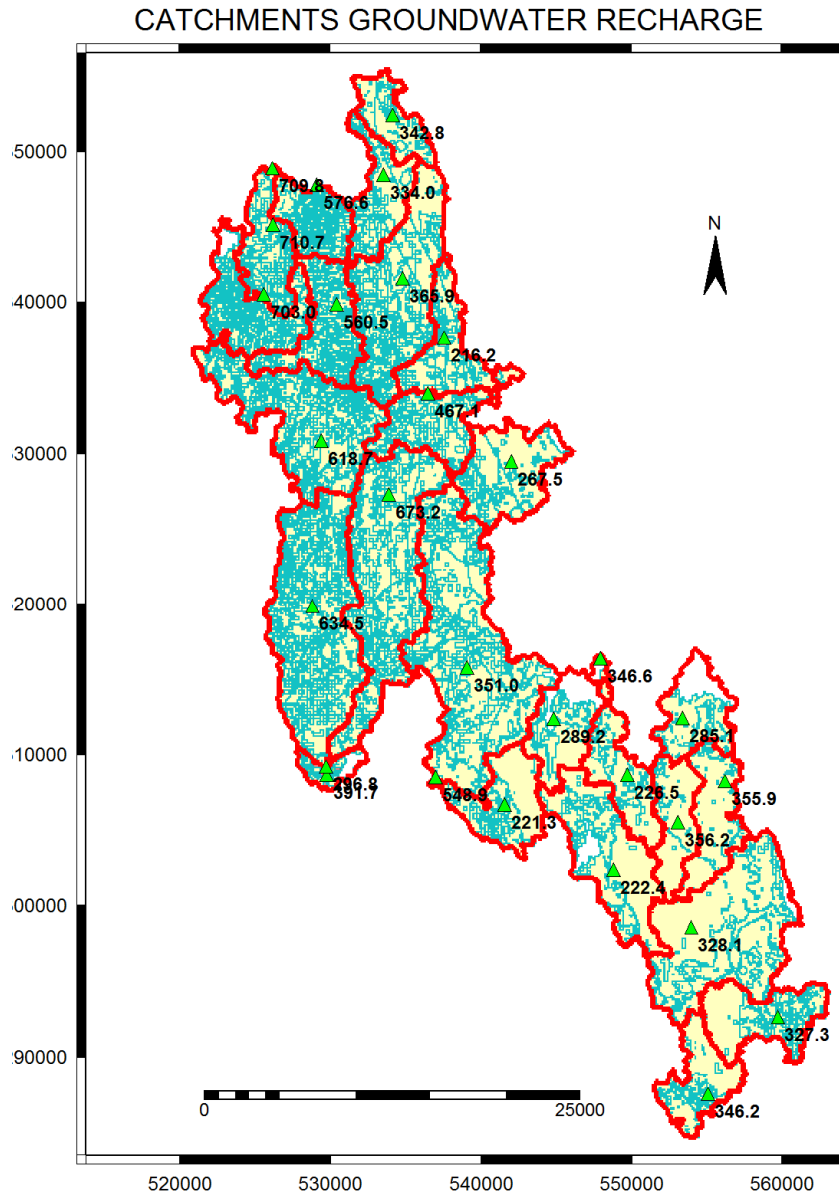


Figure 6-2 Catchment showing groundwater recharge

The model predicts well, the relation between surface runoff and recharge, whereby the catchments with high amount of surface runoff has low recharge value as illustrated in the Fig. 6-3 below. This is the function of CNs which determine amount that will infiltrate and the amount of surface runoff. Not only CNs has the consequence in determining the amount of infiltration and surface runoff but also soil depth and rooting depth.

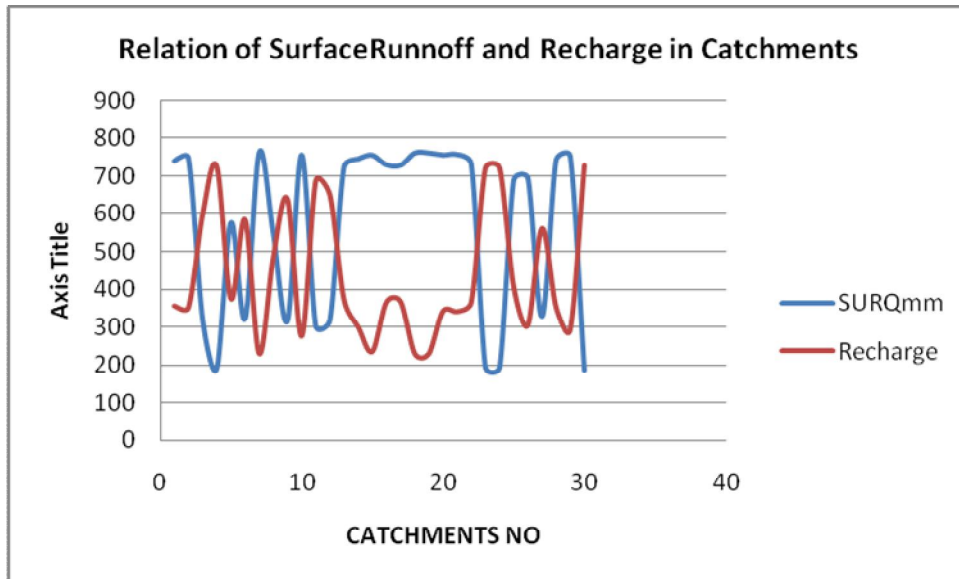


Figure 6-3 Relation between Surface runoff and Recharge

Additionally, the model predicted well relationship between evapotranspiration and recharge; it shows direct proportion relationship between these two components, see fig.6-4. This may suggest that the aquifers are shallow and ‘revap’ has big contribution to supply water from shallow aquifer zone to root zone or by direct uptake from the trees.

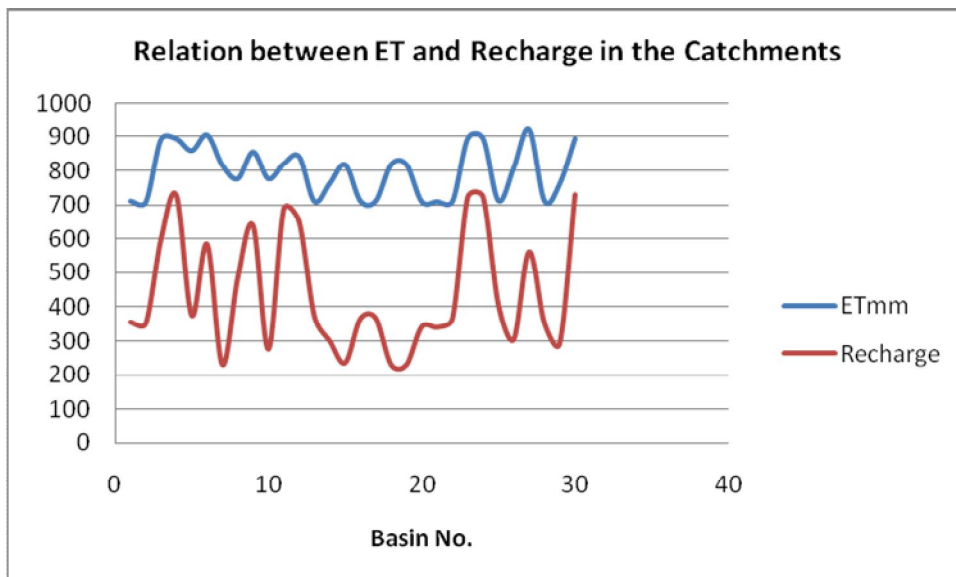


Figure 6-4 Relation between ET and Recharge in the catchments

7. Conclusion

Swat model has been applied for the first time in Unguja island to estimate the main water balance components for the island. It shows satisfactory good performance in prediction. The prediction of SWAT for this study is more or less close to the same done by previous studies, although there were some differences in area size of study. It predicted 44.1% of the rainfall evaporate to the atmosphere as evapotraspiration, 31.76% of rainfall lost as surface runoff and 23.6% infiltrate and make the total groundwater recharge.

Despite of these results, more are to be done to improve the performance of the model. As SWAT needs many input parameters for soil, groundwater, surface water, land cover data much effort must be done to collect the appropriate data for the model. Special emphasis should be on the flow data which are used for calibration

As this study is the first in hydrology, it is hoped that it will serve as the starting point for any further water resources modelling study in the study area.

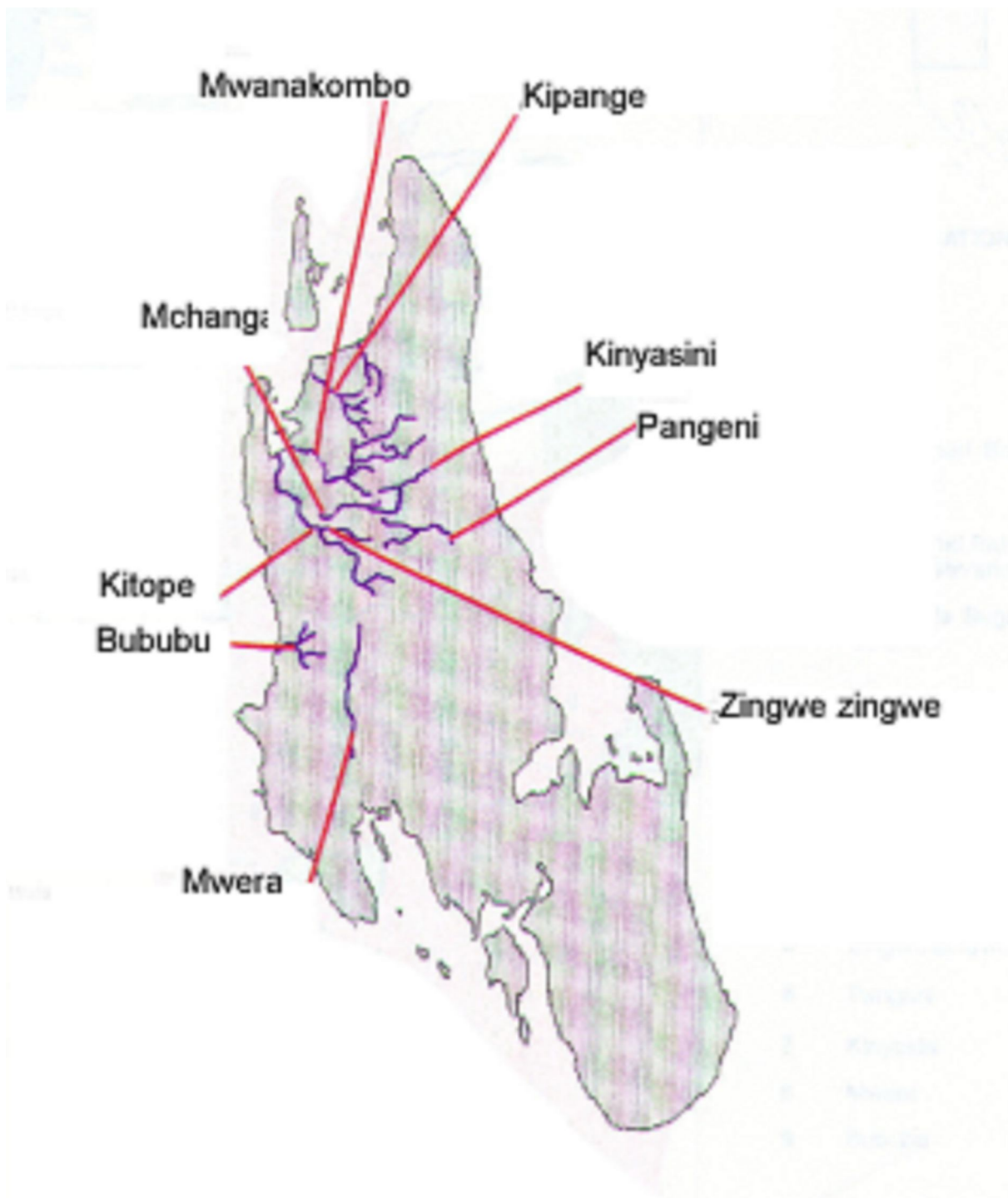
Reference

- Appelgren, B. and Klohn, W., 1999. Management of water scarcity: A focus on social capacities and options. *Physics and Chemistry of the Earth Part B-Hydrology Oceans and Atmosphere*, 24(4): 361-373.
- Arenes, A.D. and Huertas, J.F., 1986. Hydrology and Water Balance of Small Islands. A review of existing knowledge. UNESCO/IHP.
- Arthurton, R.S., Brampton, A.H., Kaaya, C.Z. and Mohamed, S.K., 1999. Late quaternary coastal stratigraphy on a platform-fringed tropical coast - a case study from Zanzibar, Tanzania. *Journal of Coastal Research*, 15(3): 635-644.
- DIWI, 1990. Engineering and Management Studies, Zanzibar and Pemba Rural Water Supply. Volume 1. United Republic of Tanzania, Zanzibar.
- FAO, 1989. Evaluation of land resources in Zanzibar, Phase I and II, Tanzania. pt. 1: Land evaluation and land suitability classification: Unguja and Pemba Islands.- pt. 2: Annex 1: Proposals for follow-up project; Annex 2: Record of data and technical specifications.
- FINNIDA, 1991. Zanzibar Urban Water Supply Development Plan. ZB/REP/4.
- Gassman, P.L., Reyes, M.R., Green, C.H. and Arnold, J.G., 2007. The Soil and Water Assessment Tool: Historical Development, Applications, and Future Research Directions,. *American Society of Agricultural and Biological Engineers*, 50(4):1211-1250.
- Gossling, S., 2001. The consequences of tourism for sustainable water use on a tropical island: Zanzibar, Tanzania. *Journal of Environmental Management*, 61(2): 179-191.
- Halcrow, 1994a. The development of water resource in Zanzibar. Report.
- Halcrow, W., 1994b. Development of Water Resources in Zanzibar, His Highness Dr Sheikh Sultan bin Mohammad Al Qasimi, Ruler of Sharjah & GOZ, Zanzibar.
- Hensel, P.R., Mitchell, S.M. and Sowers, T.E., 2006. Conflict management of riparian disputes. *Political Geography*, 25(4): 383-411.
- Hettige, M.L., 1990. Land Evaluation and land sustainability classification: Unguja and Pemba Island. Food and Agriculture Organization of the United Nation.
- Howard, H., 1994. Review of Studies on Groundwater Resources in the Project Area - Zanzibar and Pemba Rural Water Supply, Government of Zanzibar, Tanzania.
- Immerzeel, W.W. and Droogers, P., 2008. Calibration of a distributed hydrological model based on satellite evapotranspiration. *Journal of Hydrology*, 349(3-4): 411-424.
- Jayakumar, R., Duan, X.L., Kim, E. and Liu, K., 2009. The role of United Nations Educational, Scientific and Cultural Organization-International Hydrological Programme in sustainable water resources management in East Asian countries. *Journal of Geographical Sciences*, 19(3): 259-272.
- Johnson, J., 1983. Groundwater Review, Zanzibar Island. FAO, Rome, Italy.
- Johnson, J., 1987. Hydrological Map of Zanzibar.
- Kent, P.E., Hunt, J.A. and Johnstone, D.W., 1971. The geology and geophysics of coastal Tanzania. *Geophysical Paper*, 6(6).

- Klein, R., 2008. The Edaphic Landscape of Unguja Island, Zanzibar. An exploratory study on the relation between soil variability and the landscape. Turku University, Department of Geography, Publications B Nr 11.
- Kombo, Y.H. and Kitwana, M.M., 1997. Coral rag soil fertility improvement. Farmers' indigenous knowledge and practices. Commission of Natural Resources. Forestry Technical Paper No. 72. Zanzibar.
- Merka, J., 2000. Remote Sensing and GIS Application to Water Resource Assessment Management, A Case Study in the Upper River Catchment, Zimbabwe, Department of Water Resource. Enschede, ITC. MSc.
- Molle, F., 2009. WATER AND SOCIETY: NEW PROBLEMS FACED, NEW SKILLS NEEDED. *Irrigation and Drainage*, 58: S205-S211.
- Ncube, M. and Taigbenu, A.E., 2006. The impact of land cover and land use on the hydrologic response in the Olifants Catchment. MSc Research Report, University of the Witwatersrand, Johannesburg.
- Ndomba, P., Mtalo, F. and Killingtveit, A., 2008a. SWAT model application in a data scarce tropical complex catchment in Tanzania. *Physics and Chemistry of the Earth*, 33(8-13): 626-632.
- Ndomba, P., Mtalo, F. and Killingtveit, A., 2008b. SWAT model application in a data scarce tropical complex catchment in Tanzania. *Physics and Chemistry of the Earth, Parts A/B/C*, 33(8-13): 626-632.
- Neitsch, S.L., Arnold, J.G., Kiniry, J.R. and Williams, J.R., 2005. Soil and Water Assessment Tool Theoretical Documentation. USDA-ARS Grassland, Soil and Water Research Laboratory.
- Ritter, M.E., 2006. The Physical Environment: An Introduction to Physical Geography. http://www.uwsp.edu/geo/faculty/ritter/geog101/textbook/title_page.html.
- Shaghude, Y.W. and Wannas, K.O., 1995. Sediment distribution and transport in the Zanzibar channel. *Ambio*, 24(7-8): 519-522.
- Shaghude, Y.W. and Wannas, K.O., 1998. Morphology and sediment distribution of the Zanzibar Channel. *Ambio*, 27(8): 729-733.
- Stockley, G.M., 1942. The geology of the Zanzibar protectorate and its relation to the east African mainland. *Geological Magazine*, 79(4): 233-240.
- T, A.G., 1937. Review: East African Soils. *Journal of Ecology*, 25(1): 267-268.
- Tierney, J.E. and Russell, J.M., 2007. Abrupt climate change in southeast tropical Africa influenced by Indian monsoon variability and ITCZ migration. *Geophysical Research Letters*, 34(15).
- UNDTCD, 1987. Hydrogeological Map of Zanzibar Map NO. 3344, United Nations.
- UNEP, 1999. Overview of Land-based Sources and Activities Affecting the Marine, Coastal and Associated Freshwater Environment in the Eastern Africa Region. UNEP Regional Seas Reports and Studies No. 167. UNEP 1999.
- White, I. et al., 2007. Challenges in freshwater management in low coral atolls. *Journal of Cleaner Production*, 15(16): 1522-1528.
- ZAWA-AfDB-UNHABITAT, 2008. WRM strategy for Zanzibar. Draft Repot.
- ZILEM, 1995. National Land Use Plan.

Appendices

Appendix A: Location of the rivers in the study area



Appendix B-1 Min Temp (degree Centigrade)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2008												
1	25.4	25	22.8	24.5	24.2	21.7	22.5	23.2	19.2	21.3	23.7	24.3
2	25.9	24	23.1	24.6	24.4	21.3	22.7	21.2	22.3	22.5	22.6	24
3	23.3	22.9	24.9	23.3	24.6	21.9	23.4	22.7	22.3	22.3	22.2	24.8
4	23.8	24.8	23.8	23.4	24.3	23.6	19.7	22	21.3	22.4	22.5	23.9
5	25	23.8	24.5	24.1	23.8	21.6	20.1	23.1	18.8	22.1	22.5	22.8
6	24.3	24.8	25.6	23.9	24	23.2	20.3	20.9	19.6	24.1	22.5	23.6
7	24.4	25.5	24.3	24.7	21.9	23.3	19.9	23.1	19.3	23.8	23.4	22.5
8	24.4	25.9	23.8	24.9	22.8	22	17.5	21	19.6	23	22	23.5
9	25.2	25.3	23.9	23.4	22.5	23.3	22.8	22	19.2	22.1	21.1	23.4
10	23.9	25.3	23.5	23.6	22.8	23.3	21	22.3	19	22.1	23.1	23.8
11	23.4	24.8	23	23.9	22.8	23.2	19.2	24.1	18.6	22.5	23.1	23.8
12	24.6	24.4	22.8	25.1	23	23	22.3	23	21.8	24.1	24	23.5
13	23	22.5	23.4	23.8	21.9	21.7	22.3	22.7	22.7	21.1	23.2	23.9
14	23.6	22.5	25.3	24.9	23.1	22.3	23.2	19.9	23.4	21.4	23.4	24
15	23.9	24	24	25.3	24.4	23	22.3	21.1	22.8	24	23.5	23.2
16	22.6	24.1	24.3	23.1	24.4	22.8	23.8	20.4	21.3	22.6	23	23.9
17	23.3	23.8	23.6	24.1	22.2	21	21.7	20	19.8	22.1	23.2	25.1
18	24.6	24.1	24.8	24	21.4	21.7	22	21	20.3	21.7	23.9	24.8
19	25.6	25.8	25.9	24	23.9	22.4	22.2	20.5	19.9	21.4	24.4	24.9
20	23.8	25.6	26.1	23.2	24.7	22.4	23	23.7	19.7	21.1	24.4	25
21	22.9	24.6	25.8	24.2	23.6	20.5	24.3	21.6	22	20.9	23.5	24.5
22	24	24.2	25.8	23.5	23.4	19.6	23.3	22.3	23.9	20.8	23.7	23.4
23	23.9	24.4	25.9	24.1	24.3	22.3	21.3	23.1	20.9	21	23.4	23.9
24	25.6	24.1	25.8	24.7	23.6	21.8	22.7	23.3	20.7	21.5	23.4	25.2
25	24.2	22.3	24.9	24.6	22.4	20.8	22	21.2	19.9	24.5	23.8	24.4
26	26	21.9	25.2	23.4	23.1	23.1	22.2	19.4	19.9	24.3	24.2	24.3
27	23	21.3	25.1	22.4	23.8	23.1	22.5	19.9	21.8	24	24.5	23.5
28	26.2	20.4	24.2	23.6	22	20.9	21.6	19.4	20.1	22.1	24.6	23.6
29	23.3	21.6	23.5	23.2	22.3	19.8	22	20.9	20.3	23	22.9	23.8
30	23.8		25.8	23.8	23.8	22.6	23.3	19.2	24	22.3	24.5	23.9
31	24.1		24.4		22.4		23.6	19.3		23.4		23.5

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2007												
1	24.1	24	26	23.1	23.8	23.5	23	23	20.8	21.2	20.9	23.1
2	23.5	25.2	26.1	23.3	23.7	24.5	23.6	23.6	22.7	23.3	19.7	22.8
3	23.9	25.8	24.4	23.3	23.8	22.9	23.3	23.3	19.9	21.4	19.6	22.8
4	26	24.4	24.1	24.5	23.3	23.4	19.9	19.9	20.5	21.3	20	21.8
5	25.4	23.9	25.3	25.2	24.6	22.4	20.4	20.4	21.3	20.7	20.6	22.8
6	24.8	24.2	24.5	24.3	25.1	23.9	23.5	23.5	22.9	21	22	22.9
7	24.9	23.3	25.4	23.9	24.6	22.4	22.6	22.6	21.3	20.8	22.6	23.8
8	25.2	23.8	24.2	23.6	25.1	21.4	22.9	22.9	21.4	20.1	22.3	23.8
9	25.6	25.3	24.5	23.7	24.4	21.7	22.5	22.5	21.1	21.9	21.9	24.4
10	25.4	25.8	25.7	24.8	24.7	22	23.2	23.2	19.6	21.2	22.9	24.2
11	24.7	25.6	25.7	24.2	25.5	23.9	21.9	21.9	21.1	20.6	22.5	24.6
12	25.1	26.1	24.6	24.4	25.2	23.1	20.8	20.8	19.9	20.8	22.7	24.3
13	24.6	15.4	25.4	24.4	24	23.4	21	21	20.9	21	23.4	24.1
14	24.1	25.9	25.7	25.6	25.2	22	20.4	20.4	23.2	21	24.1	23.4
15	23.2	24.5	26	25.6	24.8	24.6	19.2	19.2	21.2	21.1	22.6	23.4
16	23.9	25	25.3	23.5	22.5	24.6	19.6	19.6	22.7	20.6	22	23.5
17	25.3	24	25.5	23.8	23.4	23.6	21.2	21.2	24.7	22.6	21.9	25.6
18	25.7	23.2	25.1	24.9	22.9	23.3	23.7	23.7	23	25.2	22	25.4
19	24.2	21.8	22.2	23.7	22.4	22.7	22.2	22.2	22.4	22.8	22.5	25.4
20	26.3	22.2	24.5	23.3	22	23.1	22	22	23.5	22	22.6	25
21	26.8	21.5	24.5	23.1	22.5	23.4	22.5	22.5	21.3	22.9	23.6	23.5
22	25.5	24.7	24.8	23.8	22.6	22.8	22.9	22.9	20.2	21	22.6	25.6
23	23.4	26.1	23.3	23.6	23	22.5	22.2	22.2	19.6	21	23.3	24.4
24	24.8	27.4	23.8	23.9	24.1	22.7	19.4	19.4	20.7	22.7	23.6	23.9
25	23.6	24.6	23.4	23.3	25.3	21.4	23.3	23.3	19.9	22.6	23.4	23.4
26	26.4	27.1	23.9	23.6	24.6	20.3	22.6	22.6	20.8	22.9	23.8	25.8
27	26.5	26.1	24.3	24.1	24.6	22.5	20.6	20.6	22.4	24.6	23.2	26.7
28	26.5	23.7	25.2	25	25	21.1	21.1	21.1	23.4	24.3	24.3	24.2
29	25.3		24.2	23.8	24.2	20.8	19.5	19.5	22.6	22.3	25.2	23.5
30	26.4		23.6	23.1	23.4	23	21.4	21.4	22.6	24.9	23.9	22.8
31	26.2		24.1		23.1		21.7	21.7		21.3		24.8

2006	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	24.5	25.1	26.6	25.9	24	24	23.3	20.5	23.6	20.8	23.9	24.5
2	23.6	26.8	25.2	25.9	24	24.5	22.6	19.3	23.3	22.3	24	23
3	24.7	26.4	25.7	23.9	24	23.8	21	19.7	22.5	23.8	24	23.7
4	23.4	25.1	25.8	25.7	24.5	24	20.4	19.6	23.2	23.2	24.7	23.9
5	26.2	23.4	25.7	23.2	25.1	24.3	22.7	20.1	23.9	20.8	24.4	23.7
6	26.3	23.3	25.3	24.4	25.8	23.7	22.5	20.5	21.7	20.3	24.2	23.4
7	25.2	26.4	24.3	22.6	25.5	24.3	22.2	22.1	22.4	23.2	22.8	23
8	23.5	23.4	25.6	23.8	24.8	24.3	20	22.8	20.9	20.8	23	23.6
9	22.8	22.5	24.3	24.2	23.2	21.9	23.2	22.3	22.4	20.6	25.3	23.8
10	23.3	22.6	24.4	24.8	23.4	23.4	23	21.3	22.3	21.4	24.9	24.3
11	24.3	23.3	23.4	24.6	23.3	21.5	23.1	22.4	20.2	21	23.6	24.4
12	24.4	24.4	24.6	24.2	23	21.8	22.3	20.7	22.3	21.5	22.6	23.4
13	23.4	25.2	24	23.7	24.1	21.8	21.3	20.5	20.1	20.8	22.6	23.4
14	24.6	25.4	23.5	23.3	24	21.3	22.6	22	21.1	23.6	23	23.5
15	23.2	25.6	24.5	26.4	21.1	19.6	22.7	22.1	20.4	22.8	23.3	23.7
16	25.2	24.3	23.6	25.3	23.5	22.8	23.3	23.9	21	23.5	23	24.6
17	24.2	24.4	25.5	25.5	21.9	23.8	22.8	21.3	19.8	21.5	22.5	25.5
18	23.5	24.4	25.9	26	20.8	22.3	21.9	21.4	23.4	23.2	22.7	24
19	24.2	25.2	25.1	25.2	20.7	23.2	20.8	21.7	23.4	21.7	23.5	25.8
20	23.6	23.4	24.9	25.1	20.3	22	20.1	19.1	20.9	23.9	23.6	24.7
21	24	23.9	24.5	24.6	20.4	23.3	21.9	20.9	23.3	24.8	24.4	23.8
22	25.8	22.4	24.5	25.2	23.9	22.7	20.5	20.7	22.1	21.3	23.7	24.7
23	26.6	22.7	24.8	23.1	24	21.5	19.7	20.3	22.8	23.2	23.3	22.9
24	26.5	23.6	24.5	24.6	22.9	23.8	19.9	20.1	21.9	21.5	24.7	23.5
25	25.9	26.1	24.5	25	23.7	24	19.9	19.5	19.9	22	23.4	23.7
26	23.8	25	24.4	24.5	24.1	23.3	22.6	21.3	20.4	23.6	22.6	23.7
27	24.6	24.7	25.3	25	24.4	20	22.5	19.6	20.2	23.8	24.9	26.4
28	23.6	25.5	23.5	25	24.4	23	19.9	24.3	23.4	24.1	25.5	24.6
29	24.4		23.4	23.4	25.3	22.5	21.8	21.6	23.2	23.7	24.9	25.2
30	24.2		24.8	24.2	23.8	22.6	21.7	19.8	22.2	24.3	24.1	25.1
31	24.1		24.7		23.8		22.4	20.3		24.2		25.6

Appendix B-2 Max Temp (degree centigrade)

2008	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	32.3	32.8	29.1	31.5	28.2	28.8	27.8	28.4	28.5	29.7	29.6	29.8
2	33.2	32.4	34.6	31.6	30.8	28	28.8	28.9	27.7	29.2	28.4	30.9
3	33.4	32.6	33.7	31.6	31	29.9	28.2	28.4	29.7	28.3	28.4	31.5
4	32.6	32.5	30.3	31.4	30.8	29.9	28.6	28.3	30.4	29.6	29.9	31.6
5	32	33.3	32.7	30.4	31.1	28.9	28.6	28.4	29.8	30.3	27.7	31.1
6	32.8	33.5	26.6	29.8	30.4	28	28.4	29.2	29.8	30.9	29.6	31.4
7	32.4	31.4	32.5	27.2	29.1	29.1	28.6	27.6	30.2	31.1	30.9	30.6
8	31.9	32.5	33.2	30.5	29.8	27.2	28.9	27.7	29.8	31.4	30.8	31.1
9	32.4	32.7	33	30.7	24.9	27.4	28.3	28.4	29.6	29.8	28.9	31.3
10	32.6	32.8	32.6	29.4	27.6	27.8	28.2	27.2	29.7	31	30.6	31.8
11	33.8	33.1	31.8	30.6	28.3	27.4	28.1	27.1	30.8	30.3	30.6	31.8
12	33.7	33.2	30.5	32.1	27	-99	27.9	28.5	31.2	30	31.1	30.1
13	33	33.3	30.5	31.2	29.2	-99	28	28.8	31.1	31.1	30.5	30.2
14	34.4	34.3	31.4	31.5	29.6	-99	28.8	28.6	30.6	30.4	31.4	31.6
15	34.4	34.7	29.3	31.9	29.6	-99	29	29.2	29.6	28.3	30.6	32.1
16	32.6	33.9	30.6	31.2	30.2	-99	27.8	29.3	30.3	30.1	28.8	31.7
17	31.6	32.6	31.5	31.6	30.2	-99	29.3	28.4	30.1	30.7	30	32.3
18	32.1	33.9	31.4	31.1	29.6	-99	29	29.6	28.8	31.1	30.3	32.4
19	31.9	34.3	31.2	31.5	29.6	27.4	28.8	29.3	30.1	30.8	30.1	34.3
20	32.2	32.3	32.4	31.7	30.7	27.1	29	29.5	30.4	28.9	31.3	32.1
21	32.6	33.8	32	31.4	30	28.5	28.9	29.4	30.3	30.3	29.1	32.6
22	32.7	32.5	32.7	28.7	30.2	27.7	28.6	29.5	30.1	31.7	29.1	28.6
23	32.5	33.6	31.8	31	29.6	28.9	28.6	31.1	29.4	31.4	30.5	29.8
24	32.7	35	34	31	29.2	28.8	29	30.6	30.1	30	31.6	28.5
25	32.4	38.2	27.9	31	29.7	28.7	29.2	29.2	30	32.4	30.6	29
26	32.4	33.7	32.4	27.8	28.6	28.1	29	30.4	30.9	32.4	30.7	31.8
27	33.1	34.7	30.5	28.3	28.2	28.3	28.3	30.5	29.4	30.8	31.3	32.8
28	32.9	33.5	31.1	25.8	29.5	28	28.8	29.7	29.4	31.1	30.6	32.6
29	33.8		32	29.6	29.7	28.4	29.3	29	30	31.1	29.3	27.6
30	33.3		31.9	30.6	29.1	29	27.3	29.8		31	29.4	32.6
31	32.6		31.3		29.6		28.5	30.5		29.1		29.6

Appendix B-2 continue

2008	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	19.2	16.2	4.2	19.4	7.8	15.3	13.7	12.6	14.1	19.1	10.2	9.6
2	20.3	14.5	20	17.9	19.1	15.2	19.3	17.1	16.7	15.5	8	16.5
3	17.3	18.3	15.2	21.9	19.5	16.6	16.4	15.9	20.2	10.2	8.4	17.3
4	15.9	16.8	7.9	20.4	19	15.9	17.9	16.7	19.9	13.7	10.2	16.3
5	16.9	21.6	14.9	22.1	19.4	17.4	15.6	14.1	18.3	22	5.1	14
6	16.3	18.9	6.5	11.3	14.4	10.9	17.4	15.3	19.4	21	10.2	14.1
7	16.9	16.7	16.7	7.3	9.5	16.1	16.3	11	19.4	18.6	15	12.4
8	12.4	16.8	17.8	17.6	16.1	9.5	17.6	16.3	21.2	20.3	18.9	12.9
9	18.8	20.1	16.4	18.6	6.3	8.6	15.9	12.3	16.9	11.8	13	14.5
10	20.4	22.5	14.9	8.9	9.7	11	14.1	12.4	15	19.1	16.7	17
11	18.8	23.7	14.3	14.9	9.9	9.2	15.6	11.8	20.9	18.9	16.2	14.1
12	21.3	23.7	10.1	20.7	10.1	6	12.1	18.2	20.5	17.4	18.4	12.1
13	20.3	16.7	14.5	15.9	14.5	16.7	15.5	18.1	18.3	22	15.3	11.6
14	23.8	21.5	19.3	16.3	15.2	16.8	19	17.7	6.6	17.4	19.5	18
15	22	23.5	6.1	16.3	18.8	17.5	15.6	17.4	16.1	7.8	15.2	19.4
16	10.9	22.1	15.3	20	18	16.4	12.7	16.5	18.9	20.7	9.8	13.9
17	12.7	14.7	20.2	21.8	18.2	4.4	19.1	16.9	20.1	16.7	16.1	19.2
18	17.5	18.3	17	18.7	17	10.9	16.5	20.5	12.3	18.1	11.8	21.6
19	18.7	22	16.8	20.4	15.7	10.6	16.9	19.9	14.3	16.4	11.8	22.6
20	19.6	20.6	19.5	22.2	17.9	9.2	16.1	18.9	19.6	12	21.1	16.1
21	16.1	18.6	16	20.2	17.7	15.5	16.5	19.2	18.1	17.4	11.3	17.8
22	20.8	25.7	21.9	6.5	12.2	9.5	13	16.4	20.2	20.9	11.9	7.2
23	18.6	26.1	19.3	15.5	16.3	17.5	16.5	18.9	18.6	17.5	13.7	7
24	18.2	25.4	22.8	14.7	10.4	16.3	18	18.1	21.3	19.1	20.6	7
25	17.3	25.1	6.7	17.8	8.7	17.1	17.1	15.5	18.6	20.8	14.4	10.1
26	20	11.6	20.6	4.8	9.8	17.7	18.6	20.3	19.4	20.7	18.1	15.8
27	18.9	17.3	8.5	9.2	10.4	17.8	15.2	18.2	20.2	13.4	17.4	20.1
28	19	16.3	17.4	3.1	17.7	17.7	16.8	13.9	11.5	21.3	19.6	20.2
29	23.9		17.3	12.5	17.5	20.1	16.6	13.8	13.9	21.3	9.5	5.5
30	24.7		21.4	12.9	17	14.1	10.9	16.4	20.2	14.8	10.2	20
31	18.6		15		18.9		14.7	16.9		10.1		13.4

2007	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	19.1	21.3	22.7	6.7	13.7	13.1	16.9	13.9	20.2	23.1	22.6	21.8
2	12.5	15.8	13.7	22.1	6.1	12.4	13.3	11.3	23.1	19	24	17.8
3	21.6	14.3	20.4	25.9	26.1	10.2	17.8	14.2	21.3	23	18.8	11.8
4	17.8	16.5	19.6	26.1	22.5	12.9	15.6	20	23.7	15.3	20.8	28.1
5	19.5	20.1	21.7	22.7	22	17.3	21.3	20.5	22.8	23	22.2	17.4
6	20.9	16.3	21.1	21	21.2	20.5	17.4	18.6	19.4	24	21.5	16.8
7	20.7	17.6	17.7	21.4	14.8	18.5	19.2	19.9	22.2	17.9	24.5	16.3
8	21.1	17	17.1	21.6	20.4	19.6	17.6	17.1	20.7	23.2	21	20.9
9	20.2	20.4	21.1	22.7	21	20.1	20.4	20.4	23.8	6.9	24.3	13.3
10	21	20.9	25.2	21.2	18.1	20.7	21.1	16.4	20.5	24.3	19.6	17.3
11	22.8	19.9	24.5	13.2	12.9	20.1	22.5	20.4	20.3	22.4	23.4	19.9
12	19.1	16.8	19.9	21.9	14.5	19.1	19.5	18.8	24.5	23.1	13.1	12.5
13	20.8	16.1	19.6	18.9	15.3	13.4	20.1	23.1	20.1	20.1	5.7	14.2
14	17.9	22.6	18.7	21.2	14.1	21.4	20	19.9	19.6	21.9	30.9	14.8
15	21.5	21.7	11.3	15.5	14.5	19.1	20.1	18	19.7	20.2	12.5	17.6
16	20.7	21.9	16.4	12.1	6.7	21.2	15.8	18	22.4	20	23.3	25.9
17	15.6	20.5	15.6	7.6	6.3	19.2	14.2	15.3	19.2	23.1	16.5	22.4
18	15	24.3	5.4	8	19.5	20.5	13.1	19.6	23.7	21.5	24.5	21.7
19	16	23.2	23	9.9	20.5	22	21.1	20.3	23.2	23.4	18.8	21.8
20	20	23.7	17.9	22.2	20.6	20.3	18.7	19	21.3	16.5	20.1	17.3
21	18	24.5	17.8	23.4	12.5	19.3	18.6	13.9	23.2	24.2	18.9	18
22	19.5	21.4	14.2	17.3	11.1	17.3	20.7	11.9	22	25.4	19.1	13.9
23	23.5	23.4	16.2	14.2	18	19.7	21.1	22.6	22.5	24.1	18	16.3
24	23	21.4	16.7	9.5	18.9	19.1	20.4	21.5	23.3	17.1	15.3	22.1
25	19.5	23	23	18.2	23.6	14.8	20.6	14	23.7	14.8	18.4	22.9
26	19.4	22.1	22.4	11.6	11.8	19.1	18.4	20.5	21.5	23.5	16.8	27.6
27	17.3	21.9	14.9	20.3	21.1	20.9	18.7	19.9	16.8	25	17.3	23.6
28	23.8	14.5	17.1	21.7	14.9	16.5	18.1	21.1	20.5	26.4	20.9	17.4
29	20.5		16.2	21.7	11.2	19.9	20.1	19.1	18	21.4	19.7	23.4
30	18.6		21.4	15.2	4.5	18.4	21.9	20.8	21	11.9	24.2	19.6
31	20.4		17.9		7.2		19.5	18		24.8		22

2006	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	20.9	19.2	22	19.6	16.5	18.1	18.9	15	20.6	25.7	20.3	23.6
2	21.8	18.1	21.3	14.4	21.2	20.2	16.7	9.3	15.3	13.2	12.1	19.6
3	22.9	16.8	18.1	7.9	21.7	19.6	13.3	16.7	16.5	23.1	17.4	9.5
4	24.3	23	24.8	7.9	21	18.9	12.1	18.3	11.8	19.7	19.9	15.2
5	23.7	15.2	22.5	9.7	21.3	4.9	16	19.2	22.3	22.7	5	18.1
6	23.3	16.1	18.3	21.5	19.7	16.8	20.6	19.4	21.5	20.7	11.1	22.3
7	24.4	14.1	16.3	16.4	20.3	16.4	20.9	17.1	21.2	19.4	13.8	19.9
8	21.1	20.8	17.7	11.9	21.7	19.9	19	19.4	16.6	13.9	22	11.9
9	18.9	20.6	20.5	19.1	11.5	18.7	14.5	17.3	19.9	21.5	18.1	19
10	25.3	14.5	16.7	8.1	13.5	16.8	20.8	17.9	18.1	12.6	17.4	19.6
11	18.6	16.7	16.3	19.9	18.7	19.9	18.2	15.2	19.2	16.7	14.3	16.5
12	12	13.1	17.4	11.8	15.8	18.1	20.4	14.2	20.8	21.4	16.8	19.4
13	19.9	21.1	21	21.2	20.3	17.7	19.6	12.4	21.8	13.2	18.1	18.5
14	17.3	22.4	23.6	22.6	18.1	15.5	11	20.4	18.1	22.2	14.2	20.6
15	8	20.6	20.2	17.3	18.6	13.5	14	20.9	19.9	14.2	16.3	18.2
16	10.3	21.5	24	16.5	11.9	13.8	13.3	21.1	16.5	19.4	14.7	17.3
17	18.6	22.6	22.6	5.7	10.1	8.8	11.3	17.9	15.2	18	13.9	19.7
18	19.9	21.3	25.4	11.9	10.6	14.9	16.5	14.1	19.6	20.9	18.4	19.6
19	14.3	20.4	24.5	7.8	18.5	15.2	18	18	21.3	23.8	19.9	20.5
20	14.2	18	25	9.9	14.7	15.9	15.8	14.7	18.1	25.4	19.9	19
21	17.3	18.8	24.5	15.7	19.6	10.7	13.1	17.1	19.6	21.3	20	16.9
22	15.8	18.1	27.1	22.7	19.9	13.4	8.3	21.4	18	20.3	21.5	17.7
23	23.2	18.7	25.6	18.1	20.3	18.6	12.2	21.5	19.7	22.9	19.9	19.6
24	19.4	19.1	20.2	20.7	12.9	18.1	20.9	16.2	17.3	24.8	22.8	19.6
25	22	24	25.9	18.3	18.6	21	14.8	7.1	16.7	22.6	19.6	18.4
26	18.9	20.7	24.2	9.8	19.2	18.4	15.9	12.9	19.4	17.9	17	11.4
27	11.3	25.4	16.5	17.8	19.2	16.1	15.9	22.2	13.9	13	19	16.8
28	19	26.6	15.5	6.2	10.2	19.7	18.2	22.2	19.6	17.9	7.2	18.9
29	21.9	25.7	21.6	7.3	15.5	20.4	18.1	17.5	18	19.4	9.6	19.6
30	17		22	18.6	15.5	19	15.6	19.3	21.1	22.8	11.6	21.5
31	14.9		24.8		17.3		17.1	18.9		17.8		19.1

Appendix B-3 Solar Radiation (MJM⁻²)

2008	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	19.2	16.2	4.2	19.4	7.8	15.3	13.7	12.6	14.1	19.1	10.2	9.6
2	20.3	14.5	20	17.9	19.1	15.2	19.3	17.1	16.7	15.5	8	16.5
3	17.3	18.3	15.2	21.9	19.5	16.6	16.4	15.9	20.2	10.2	8.4	17.3
4	15.9	16.8	7.9	20.4	19	15.9	17.9	16.7	19.9	13.7	10.2	16.3
5	16.9	21.6	14.9	22.1	19.4	17.4	15.6	14.1	18.3	22	5.1	14
6	16.3	18.9	6.5	11.3	14.4	10.9	17.4	15.3	19.4	21	10.2	14.1
7	16.9	16.7	16.7	7.3	9.5	16.1	16.3	11	19.4	18.6	15	12.4
8	12.4	16.8	17.8	17.6	16.1	9.5	17.6	16.3	21.2	20.3	18.9	12.9
9	18.8	20.1	16.4	18.6	6.3	8.6	15.9	12.3	16.9	11.8	13	14.5
10	20.4	22.5	14.9	8.9	9.7	11	14.1	12.4	15	19.1	16.7	17
11	18.8	23.7	14.3	14.9	9.9	9.2	15.6	11.8	20.9	18.9	16.2	14.1
12	21.3	23.7	10.1	20.7	10.1	6	12.1	18.2	20.5	17.4	18.4	12.1
13	20.3	16.7	14.5	15.9	14.5	16.7	15.5	18.1	18.3	22	15.3	11.6
14	23.8	21.5	19.3	16.3	15.2	16.8	19	17.7	6.6	17.4	19.5	18
15	22	23.5	6.1	16.3	18.8	17.5	15.6	17.4	16.1	7.8	15.2	19.4
16	10.9	22.1	15.3	20	18	16.4	12.7	16.5	18.9	20.7	9.8	13.9
17	12.7	14.7	20.2	21.8	18.2	4.4	19.1	16.9	20.1	16.7	16.1	19.2
18	17.5	18.3	17	18.7	17	10.9	16.5	20.5	12.3	18.1	11.8	21.6
19	18.7	22	16.8	20.4	15.7	10.6	16.9	19.9	14.3	16.4	11.8	22.6
20	19.6	20.6	19.5	22.2	17.9	9.2	16.1	18.9	19.6	12	21.1	16.1
21	16.1	18.6	16	20.2	17.7	15.5	16.5	19.2	18.1	17.4	11.3	17.8
22	20.8	25.7	21.9	6.5	12.2	9.5	13	16.4	20.2	20.9	11.9	7.2
23	18.6	26.1	19.3	15.5	16.3	17.5	16.5	18.9	18.6	17.5	13.7	7
24	18.2	25.4	22.8	14.7	10.4	16.3	18	18.1	21.3	19.1	20.6	7
25	17.3	25.1	6.7	17.8	8.7	17.1	17.1	15.5	18.6	20.8	14.4	10.1
26	20	11.6	20.6	4.8	9.8	17.7	18.6	20.3	19.4	20.7	18.1	15.8
27	18.9	17.3	8.5	9.2	10.4	17.8	15.2	18.2	20.2	13.4	17.4	20.1
28	19	16.3	17.4	3.1	17.7	17.7	16.8	13.9	11.5	21.3	19.6	20.2
29	23.9		17.3	12.5	17.5	20.1	16.6	13.8	13.9	21.3	9.5	5.5
30	24.7		21.4	12.9	17	14.1	10.9	16.4	20.2	14.8	10.2	20
31	18.6		15		18.9		14.7	16.9		10.1		13.4

2007	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	19.1	21.3	22.7	6.7	13.7	13.1	16.9	13.9	20.2	23.1	22.6	21.8
2	12.5	15.8	13.7	22.1	6.1	12.4	13.3	11.3	23.1	19	24	17.8
3	21.6	14.3	20.4	25.9	26.1	10.2	17.8	14.2	21.3	23	18.8	11.8
4	17.8	16.5	19.6	26.1	22.5	12.9	15.6	20	23.7	15.3	20.8	28.1
5	19.5	20.1	21.7	22.7	22	17.3	21.3	20.5	22.8	23	22.2	17.4
6	20.9	16.3	21.1	21	21.2	20.5	17.4	18.6	19.4	24	21.5	16.8
7	20.7	17.6	17.7	21.4	14.8	18.5	19.2	19.9	22.2	17.9	24.5	16.3
8	21.1	17	17.1	21.6	20.4	19.6	17.6	17.1	20.7	23.2	21	20.9
9	20.2	20.4	21.1	22.7	21	20.1	20.4	20.4	23.8	6.9	24.3	13.3
10	21	20.9	25.2	21.2	18.1	20.7	21.1	16.4	20.5	24.3	19.6	17.3
11	22.8	19.9	24.5	13.2	12.9	20.1	22.5	20.4	20.3	22.4	23.4	19.9
12	19.1	16.8	19.9	21.9	14.5	19.1	19.5	18.8	24.5	23.1	13.1	12.5
13	20.8	16.1	19.6	18.9	15.3	13.4	20.1	23.1	20.1	20.1	5.7	14.2
14	17.9	22.6	18.7	21.2	14.1	21.4	20	19.9	19.6	21.9	30.9	14.8
15	21.5	21.7	11.3	15.5	14.5	19.1	20.1	18	19.7	20.2	12.5	17.6
16	20.7	21.9	16.4	12.1	6.7	21.2	15.8	18	22.4	20	23.3	25.9
17	15.6	20.5	15.6	7.6	6.3	19.2	14.2	15.3	19.2	23.1	16.5	22.4
18	15	24.3	5.4	8	19.5	20.5	13.1	19.6	23.7	21.5	24.5	21.7
19	16	23.2	23	9.9	20.5	22	21.1	20.3	23.2	23.4	18.8	21.8
20	20	23.7	17.9	22.2	20.6	20.3	18.7	19	21.3	16.5	20.1	17.3
21	18	24.5	17.8	23.4	12.5	19.3	18.6	13.9	23.2	24.2	18.9	18
22	19.5	21.4	14.2	17.3	11.1	17.3	20.7	11.9	22	25.4	19.1	13.9
23	23.5	23.4	16.2	14.2	18	19.7	21.1	22.6	22.5	24.1	18	16.3
24	23	21.4	16.7	9.5	18.9	19.1	20.4	21.5	23.3	17.1	15.3	22.1
25	19.5	23	23	18.2	23.6	14.8	20.6	14	23.7	14.8	18.4	22.9
26	19.4	22.1	22.4	11.6	11.8	19.1	18.4	20.5	21.5	23.5	16.8	27.6
27	17.3	21.9	14.9	20.3	21.1	20.9	18.7	19.9	16.8	25	17.3	23.6
28	23.8	14.5	17.1	21.7	14.9	16.5	18.1	21.1	20.5	26.4	20.9	17.4
29	20.5		16.2	21.7	11.2	19.9	20.1	19.1	18	21.4	19.7	23.4
30	18.6		21.4	15.2	4.5	18.4	21.9	20.8	21	11.9	24.2	19.6
31	20.4		17.9		7.2		19.5	18		24.8		22

2006	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	20.9	19.2	22	19.6	16.5	18.1	18.9	15	20.6	25.7	20.3	23.6
2	21.8	18.1	21.3	14.4	21.2	20.2	16.7	9.3	15.3	13.2	12.1	19.6
3	22.9	16.8	18.1	7.9	21.7	19.6	13.3	16.7	16.5	23.1	17.4	9.5
4	24.3	23	24.8	7.9	21	18.9	12.1	18.3	11.8	19.7	19.9	15.2
5	23.7	15.2	22.5	9.7	21.3	4.9	16	19.2	22.3	22.7	5	18.1
6	23.3	16.1	18.3	21.5	19.7	16.8	20.6	19.4	21.5	20.7	11.1	22.3
7	24.4	14.1	16.3	16.4	20.3	16.4	20.9	17.1	21.2	19.4	13.8	19.9
8	21.1	20.8	17.7	11.9	21.7	19.9	19	19.4	16.6	13.9	22	11.9
9	18.9	20.6	20.5	19.1	11.5	18.7	14.5	17.3	19.9	21.5	18.1	19
10	25.3	14.5	16.7	8.1	13.5	16.8	20.8	17.9	18.1	12.6	17.4	19.6
11	18.6	16.7	16.3	19.9	18.7	19.9	18.2	15.2	19.2	16.7	14.3	16.5
12	12	13.1	17.4	11.8	15.8	18.1	20.4	14.2	20.8	21.4	16.8	19.4
13	19.9	21.1	21	21.2	20.3	17.7	19.6	12.4	21.8	13.2	18.1	18.5
14	17.3	22.4	23.6	22.6	18.1	15.5	11	20.4	18.1	22.2	14.2	20.6
15	8	20.6	20.2	17.3	18.6	13.5	14	20.9	19.9	14.2	16.3	18.2
16	10.3	21.5	24	16.5	11.9	13.8	13.3	21.1	16.5	19.4	14.7	17.3
17	18.6	22.6	22.6	5.7	10.1	8.8	11.3	17.9	15.2	18	13.9	19.7
18	19.9	21.3	25.4	11.9	10.6	14.9	16.5	14.1	19.6	20.9	18.4	19.6
19	14.3	20.4	24.5	7.8	18.5	15.2	18	18	21.3	23.8	19.9	20.5
20	14.2	18	25	9.9	14.7	15.9	15.8	14.7	18.1	25.4	19.9	19
21	17.3	18.8	24.5	15.7	19.6	10.7	13.1	17.1	19.6	21.3	20	16.9
22	15.8	18.1	27.1	22.7	19.9	13.4	8.3	21.4	18	20.3	21.5	17.7
23	23.2	18.7	25.6	18.1	20.3	18.6	12.2	21.5	19.7	22.9	19.9	19.6
24	19.4	19.1	20.2	20.7	12.9	18.1	20.9	16.2	17.3	24.8	22.8	19.6
25	22	24	25.9	18.3	18.6	21	14.8	7.1	16.7	22.6	19.6	18.4
26	18.9	20.7	24.2	9.8	19.2	18.4	15.9	12.9	19.4	17.9	17	11.4
27	11.3	25.4	16.5	17.8	19.2	16.1	15.9	22.2	13.9	13	19	16.8
28	19	26.6	15.5	6.2	10.2	19.7	18.2	22.2	19.6	17.9	7.2	18.9
29	21.9	25.7	21.6	7.3	15.5	20.4	18.1	17.5	18	19.4	9.6	19.6
30	17		22	18.6	15.5	19	15.6	19.3	21.1	22.8	11.6	21.5
31	14.9		24.8		17.3		17.1	18.9		17.8		19.1

Appendix B-4 Wind speed (m/s)

2008	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	8.3	11.8	4.3	6.4	7	10.6	8.7	4.3	15.4	5.5	4.7	4.4
2	7.6	13	7.5	7.2	7.3	8.4	6	2.8	12.5	5	1.8	5.7
3	8.1	12.9	4.9	8.3	7.1	6.8	5.7	2.3	10.3	3.5	1.9	4.1
4	7.9	8.4	4.2	7	7.5	9.5	5.8	2.3	12.6	5.1	3.7	4.5
5	8.8	6.3	5.4	6.1	9.6	11.1	8.4	2.7	12.1	6.1	5.7	2.9
6	7.5	5.2	2	5.6	7.5	9.7	7.1	2.5	8.2	8.5	6.6	3.6
7	7.7	3.3	3.3	3.5	7.4	8.9	5.3	9.3	9	7.6	5.5	3.7
8	4.9	4.4	5.7	5	9.9	8.6	6.5	10.2	8.1	2.9	6.2	5.6
9	5.6	5	6.7	3.8	8.7	4.4	10.3	5.5	8.2	1.6	9.5	7
10	3.6	3.5	3.1	3.3	8.2	5.5	9.8	7.7	5.4	6.7	6.3	7.3
11	4.3	5	3.7	2.3	9.2	2.1	9.7	4.5	8.1	5.9	4.3	5
12	7.4	3.4	3.5	3.4	6.9	6.9	6.2	6.2	4.1	8	3.6	3.2
13	4.7	3.9	2.6	2.9	7.1	7.2	7.9	7.9	4.6	6.6	2.1	0.4
14	5.8	4.3	5.3	4.2	5.2	4.5	9.2	8.5	5.3	10.3	2.7	2.5
15	3.5	5.4	2	6.9	5.2	4	8.8	10.4	4.1	11.9	2.5	3.3
16	2.3	4.1	5.6	7.5	3.5	7.3	7.8	6.9	5.5	12	2.4	4.3
17	1.8	3.4	7.2	8.5	3.7	6.3	5.7	7.9	5.6	7	2.5	6.8
18	3	4.9	7.6	9.9	2.7	8.3	4.4	11.6	5.9	8.8	2.5	6.4
19	4	5.5	6	9.1	2.9	10.2	5.8	7	8.6	8.7	2.3	4.5
20	3.5	4.2	3.4	8.5	2.2	8.1	4.1	7.3	9.3	10.3	6.7	6.3
21	8.7	5.9	3.7	7.4	2.9	7.5	5	5.2	7.5	5.8	1.6	2.6
22	9.4	4	2.4	2.5	5.2	6.2	4.4	4.1	12.5	5.5	2.4	0.2
23	12.3	4.9	2.7	3.4	6.8	6.4	4	4.5	11.1	4	2.6	3.3
24	11.1	4.1	2.9	4.7	7.3	10.3	6.2	4.6	7.9	1.5	4.4	3.3
25	8.6	4.1	3.1	6.4	4.5	11.9	6.4	3.5	2.7	3.7	2.6	2.3
26	6.5	4.6	2.6	4	5.7	8.9	7.8	3.9	3.5	5.6	3.6	7.6
27	5.6	6.8	2.9	8.3	7.9	10.3	10.5	7.1	5.8	8.3	6.6	8.2
28	6	7.8	3.3	10.8	8.2	9	7.8	8.6	8.7	9	2.7	6.3
29	6		3.7	7.5	10	8	8.9	4.1	9.1	8.9	2.5	1.7
30	5.9		7.5	5.7	10.6	10.8	6.1	3.6	5.8	8.8	3.6	4.5
31	8.4		6.6		9.8		5.5	10.1		2.8		6.6

2007	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	9.1	6	6.2	3.8	7.9	5.7	7.2	11.5	6.4	9.1	7.7	5.7
2	7.5	7.3	4.2	3.7	6	8.6	10.8	7.6	6.8	7.2	8.1	3.5
3	12.8	5.2	6.1	4.2	5.2	7.4	11.6	8.9	5.8	8	4	3.6
4	10.5	6	5.4	4.3	7.6	5.5	10.8	6.9	6.8	6.5	3.7	4
5	9.6	5.9	6.8	4.3	8.3	7.9	8.4	9	9	6.2	5	3.2
6	9.7	5.8	8	3.9	6.8	4.4	8.6	11.1	6.1	7	5.4	3.4
7	6.7	6.2	5.5	2.7	3.8	4.6	7.9	10.9	6.1	5.9	4.5	5.3
8	8.7	7.4	2.6	2.9	7.9	3.4	7.3	9	6.2	5.1	5.2	6.2
9	6.3	6	5.5	3.3	9.4	4.4	10.6	11.5	6.5	5	4	3.7
10	10.9	6.7	6.9	5.1	7.9	4.6	9.6	10.1	6	7.3	3.9	3.3
11	6.4	10.7	3.4	3.5	8.3	5.8	10.5	8.1	5.1	4.9	4.4	4.6
12	8	8.7	4.8	8.5	8.3	8.2	6	6.7	5.8	5.6	5.2	4.7
13	6.6	6.8	4.3	7.1	10.7	7.9	9.6	5.9	7.3	5.6	4.2	4.3
14	5.1	7.7	3.9	8.9	7.6	9.2	10.9	4.3	5.3	5.7	2.9	4.9
15	3.9	5.2	2.5	9.1	8.1	9.5	11.6	3.8	7.3	4.1	3.9	6.2
16	4.9	5.1	3	6.6	7.3	12.9	9.8	3.9	9.9	4.9	5.5	6.4
17	4.5	5.2	4.4	6.1	7.3	10.9	9.3	7.3	9.1	7.2	3.3	8.4
18	6.8	6.5	2.7	5.2	4.7	11.7	10.1	10.7	8.3	9.3	3.6	9.3
19	7.2	4.6	4.3	4.2	5.2	10.1	9.4	14.1	9.4	7	4.4	7.8
20	8.7	7.3	3.2	4.2	4	12.2	8	8.6	9.6	6.3	4.2	4.6
21	8.7	7.5	2.1	4.4	1.4	9.3	8	8.3	9.3	7.2	3.8	5.7
22	7.5	7.8	2.6	4.9	1.5	10.5	8.3	8.1	7.7	4.6	3.8	4.3
23	6.3	8.2	2.2	3.9	4.2	11	10.2	7.7	6.7	4.7	4.1	5.6
24	6.5	5	2.7	2.8	7.3	8.9	9.8	7.7	5.9	4	3.8	6.2
25	7.5	6.5	4	2	10.8	5.8	7.2	6.9	7.1	4.5	5.9	7.3
26	6.6	8	3.3	2.3	13.6	7.4	5.7	8.5	6.9	7.2	4.3	12.8
27	6.9	5.3	4.1	3	11.6	6	5.4	5.6	7.8	9.3	5.9	12.1
28	6.9	4.3	7.9	4.3	10.1	4	4.8	5.5	9	8.4	6.3	7
29	6.9		2.1	4.7	10	6.2	3.7	6.6	7.9	7.2	5.1	7.4
30	6.6		6.4	3.4	7.9	7.5	4.5	7.4	9.3	7.1	5.8	8
31	8.4		5.8		6.2		12.3	4.9		5.8		10.6

	2006 JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	9.9	7.6	4.6	8.9	6.5	1.1	9.8	5.9	8.2	6	6.2	3.9
2	9	5.3	5.5	6.6	8.4	2.6	8	6.3	9.3	4.2	3	4.5
3	8.1	8.5	9.6	3.5	9.2	3.5	3.9	9.2	3.9	8.8	4	1.9
4	7.9	7	6	6.7	7.8	2.7	2.5	11.4	5.4	8.9	3.6	2.1
5	7.5	4.8	6.8	8.3	5.5	0.8	4.5	9.2	4.9	8	3	3.3
6	6.9	4.9	5	6.8	3.6	3.1	5.2	9.1	6	7.9	1.7	4.2
7	8.3	8.3	3.6	5.3	2.3	4.5	5.9	8.6	5.7	8.1	2.6	3.9
8	8.5	9.6	6.9	5.9	4.6	3.2	7.4	6.5	3.9	2.6	5.4	3.2
9	10.7	9.9	6.1	5.6	1.1	4.5	9.3	8.7	3	5.3	3.6	4.7
10	8	7.6	2.9	5.9	1.7	3.1	4.8	11.5	5.2	3.7	3.3	4.8
11	4.9	6.7	2.7	6.7	4	5.1	6.3	13.1	6.3	8.2	2.4	5.1
12	3.6	5.7	4	4.9	3.3	5.4	9.1	10.3	10.6	8.5	4.2	5.3
13	4.2	7.2	4	6.9	3.7	3.7	9.5	5.6	10	3.5	4	9
14	4.3	3.9	4.6	6.8	5.5	5.7	9.3	6.1	11.5	4.1	4.8	5.4
15	3.7	3.9	3.5	7.3	7	6.3	10.1	7.7	8.5	6.1	3.6	6.5
16	2.3	4.7	4.3	5.7	7.5	6.9	10.7	7.5	5	6.9	3.9	5.8
17	4.4	6.7	3.9	5.6	7	7.7	10.7	5.8	3.9	4.3	3.6	6.5
18	7.1	10.8	7.9	9.6	10.4	5.3	10.9	6.1	5.4	4.9	6.3	7
19	6.8	12	8.8	3.8	8.9	7.5	9.9	10.7	4.7	4.9	7.3	6.6
20	4	7.5	9.5	5.3	5.8	4.8	10.7	9.4	4.1	5.3	3.5	6.6
21	2.8	6.3	7.3	4.4	5.3	4	12.1	9.9	6.1	3.9	4.1	7
22	4.2	5	5.9	5.8	5.7	3.7	4.7	11.6	8.6	3.1	5.2	6.5
23	5.9	8.4	8.2	8.1	4.4	6.4	9.4	10.5	5.6	4	3.9	6.9
24	6.2	6.5	4.7	9.4	3	4	11.3	7.5	4.9	6.3	5.4	6.8
25	7.3	6.1	4.8	11.1	3.5	6	9.4	3.9	6.7	8.1	6.7	6.2
26	7.3	5.5	4.7	5.1	3.7	4.8	8.2	4	6.7	9.5	4.4	4.1
27	7.9	3.8	4.5	3.6	5.1	4.9	7.7	5.3	5.4	2.6	5.1	6.3
28	8.7	4.3	6	5.6	2.8	3.4	7.7	7.3	5.6	3.2	3.7	6.3
29	6.4	4.1	6.5	7.1	2.9	7.9	10.2	5.6	7.8	3.9	2.9	6.5
30	5.5		8.4	5.3	4.1	10.7	11.3	5.8	7.4	5.6	1.2	6.5
31	5.7		8.5		3.3		11.7	4.6		5.1		8.9

Appendix B-5 Relative Humidity (%)

2008	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1	73	73	63	58	78	70	67	64	68	65	64	63
2	62	61	58	66	73	75	58	66	82	84	69	68
3	52	58	68	79	76	69	61	67	60	70	65	62
4	69	61	57	68	70	67	66	66	90	68	64	59
5	68	62	62	62	74	67	69	62	71	64	62	63
6	61	62	67	60	78	67	66	86	65	72	60	61
7	64	55	56	57	69	73	68	60	73	70	73	64
8	67	62	56	57	70	69	68	65	73	67	66	64
9	61	56	62	59	63	72	68	66	80	63	73	70
10	64	58	60	67	63	67	76	83	66	64	66	67
11	65	64	62	66	70	68	69	78	71	72	69	67
12	73	62	64	61	74	56	69	66	62	68	69	68
13	61	63	67	71	76	57	67	59	69	64	61	69
14	66	63	63	70	74	61	65	70	69	72	58	68
15	66	64	63	70	87	65	71	65	67	63	64	71
16	60	63	61	71	85	66	70	63	70	66	64	68
17	60	61	59	65	70	65	61	63	82	75	68	66
18	63	68	64	58	77	71	60	52	70	69	63	70
19	58	58	62	64	68	59	55	53	62	63	69	70
20	60	58	63	73	84	67	64	60	74	68	68	76
21	52	66	57	66	86	68	59	63	64	62	58	74
22	62	63	58	66	94	73	59	62	63	72	74	69
23	62	60	60	62	84	74	73	65	60	64	89	74
24	56	58	62	68	79	70	72	56	58	74	74	67
25	61	57	61	68	66	69	76	60	56	69	75	69
26	58	61	72	62	66	68	72	90	53	63	78	72
27	61	58	60	56	72	71	66	54	56	72	76	64
28	51	63	84	77	70	71	67	57	63	86	70	72
29	58		76	67	68	66	68	68	62	66	73	68
30	63		80	74	70	68	72	53	64	58	67	68
31	54		64		71		69	81		72		63

WATER BALANCE ASSESSMENT IN UNGUJA ISLAND, ZANZIBAR, TANZANIA

2007	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1	68	58	72	77	82	69	63	67	58	80	77	87
2	67	62	63	69	76	54	60	60	65	75	65	71
3	64	66	61	69	80	66	62	73	64	73	77	70
4	64	67	72	73	92	72	63	63	60	67	72	74
5	72	70	63	68	74	64	46	73	76	70	71	57
6	68	71	63	71	76	69	56	64	82	71	66	67
7	64	66	62	81	90	72	84	42	67	82	66	64
8	71	58	69	75	89	57	65	54	86	68	62	66
9	71	71	70	72	81	62	63	52	65	70	94	72
10	64	79	56	72	78	68	69	54	65	72	92	69
11	65	65	61	87	90	69	61	79	63	65	71	63
12	64	68	60	81	76	63	63	63	79	78	75	72
13	70	69	65	87	7	69	65	59	83	74	76	68
14	70	68	67	80	74	63	66	64	78	96	69	78
15	75	73	64	93	60	68	93	79	55	82	71	84
16	67	68	68	84	58	62	84	75	89	77	73	72
17	68	69	92	95	77	67	67	87	76	69	83	96
18	63	71	82	91	90	62	63	70	75	71	74	72
19	58	72	91	75	83	60	64	46	87	70	78	67
20	67	60	76	89	81	63	62	82	85	88	74	64
21	64	71	71	91	92	61	60	56	64	70	70	81
22	70	73	90	80	99	57	69	71	80	79	71	82
23	68	76	69	84	78	62	64	80	76	58	66	86
24	70	60	73	88	87	63	65	66	80	67	57	85
25	69	58	64	82	74	58	53	89	81	74	72	65
26	67	60	70	82	77	70	77	55	70	87	73	67
27	67	57	66	72	72	54	59	51	73	72	66	64
28	72	61	71	81	89	61	63	46	69	69	70	67
29	72	67	69	75	79	55	62	59	66	73	70	71
30	85		72	83	80	54	60	45	84	69	69	61
31	73		53		69		68	59		78		74

2006	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1	69	66	71	68	72	62	55	60	59	74	55	70
2	69	68	68	63	72	64	62	67	8	59	57	96
3	70	57	70	72	82	64	68	65	52	70	70	63
4	66	68	69	66	81	61	82	74	55	62	76	62
5	69	69	65	68	80	67	58	65	50	56	70	54
6	70	68	73	66	63	69	57	60	53	62	55	84
7	92	69	70	86	64	50	64	57	45	68	60	78
8	92	67	52	96	73	51	63	60	90	54	63	65
9	74	67	50	79	66	68	63	90	70	54	68	60
10	69	66	55	79	69	52	57	65	66	53	70	52
11	69	64	48	80	82	60	72	52	58	55	66	55
12	64	67	63	81	64	47	57	58	49	64	61	57
13	64	67	61	81	76	76	75	55	54	74	63	71
14	68	67	60	85	71	64	66	55	63	59	67	53
15	70	63	61	92	67	59	65	50	50	65	62	53
16	62	69	88	89	66	65	62	54	49	55	58	81
17	67	64	86	89	67	59	60	48	53	56	57	74
18	66	69	82	72	53	60	59	68	61	61	57	62
19	67	68	91	90	64	66	65	57	56	74	56	57
20	75	69	63	75	75	69	65	62	51	72	56	56
21	82	68	69	82	92	56	62	64	67	73	59	69
22	76	67	65	79	69	70	61	55	63	63	57	68
23	69	67	72	77	72	71	58	53	63	58	61	54
24	61	70	63	77	83	53	63	57	57	58	61	67
25	67	65	74	75	88	62	65	94	56	62	55	58
26	62	69	67	72	84	61	49	84	60	81	62	60
27	84	69	67	66	70	82	49	90	59	71	56	57
28	71	65	63	70	63	79	47	59	62	98	55	55
29	74		66	87	75	75	63	69	59	91	64	51
30	64		88	71	75	67	56	50	83	51	53	63
31	67		67		68		59	58		54		70

Appendix B-6 Rainfall (mm)

2008	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
		0	0	4.1	9.9	0	0	0	2	0	0	56
1	0	0	30.2	34	0	0	0	39	16.4	0	7	3.6
2	0	0	5.3	9.3	0	4	0	21.2	7.3	0	19.2	0
3	0	0	0	91.5	0.3	0	0	4	5.3	0.2	0	3.5
4	0	0	11.3	12.7	0	0	1.7	0	1.2	0	57.7	0
5	0	0	0.6	22.8	0	0	0	0	5.8	1.6	29.1	0
6	0	0	0	0	0	0.5	0	0	0	30.8	9.2	64
7	0	0	0	12	0	0	1.4	0	2.5	6.6	2	7.4
8	44.6	0	0	15.3	0	0	18.7	0	0	3.1	0.8	27.5
9	32.1	0	2.2	49.2	0	0.4	0.4	0	0.7	0	0	0
10	0	0	2.6	32.2	0	0	0.2	4.5	0	0	0	0
11	15.8	0	0	61.1	0	0	0	4.2	0	0	7.2	0
12	5.2	0	0	6.2	0	0		52.3	3	0	0.8	14.1
13	11	0.2	0	3.1	0	0	0	2	13.2	3.9	0	0
14	0.5	0	1.4	14.4	0	0	0	0	1.4	0	7.8	0
15	0	3.3	0	0	0	0	3.6	0	59.5	20.6	34.2	0
16	0	0	0	7.7	14.9	1.1	20.7	0.6	15.3	0	1.8	0
17	0	0	1.4	66.8	28.4	0	1.1	0	3.5	0	1	0
18	0	0	4.2	7.8	31.9	0	0	0	0	0	30.4	34.5
19	0	0		17.2	59.3	0	0	0	1.4	0	0	11.6
20	0	0.4	8.9	37.4	19.6	0	0	0	0	0	0	13.3
21	0	0	0.2	9.5	0.8	0	0	0	1.2	9.2	0	0.2
22	0	0.6	28	0.3	0	0.4	0	1	0	6.5	0	25.3
23	0	0.8	1.9	1	0	1.1	0.8	10.5	0	0	0	0
24	21.6	0	5	1.4	1.5	0	0	5.6	0	3	0	21.5
25	30.6	54.3	2.3	0.3	1.9	0	1.8	0	0	9	9.9	0
26	0	15.3	0	30	6.8	0	13.2	1	0.6	0	0	0
27	0	3	0.7	4.1	0.5	0	1.7	0	2.7	33.3	10.3	0
28	0		58	10.6	0	21.6	4	7.1	6.1	12	0	0.7
29	0		19.8	5	0	14.9	0.9	15.3		0	23.6	0
30	0		84.4		0		3.4	1.6		19.4		0
31	0	0	0	1.6	0		0	0.6	0	4.9	37.4	0

WATER BALANCE ASSESSMENT IN UNGUJA ISLAND, ZANZIBAR, TANZANIA

2007	1	0	0	0	1.6	0	0	0.6	0	4.9	37.4	0
	2	0	0	0	0.7	0	0	2.3	0	0.9	7.4	0
	3	0	0	0	0	0	0	1	0	1.4	0	0
	4	0	0	0	12.6	0	2	0	0	8.3	0	0
	5	1.1	0	0	0	30.6	1.3	0	0	2.9	0	5.4
	6	2.9	0	1.5	0	8.5	0	1.5	0	0	0	0
	7	1	0	0	0	5.3	0	0	0	0	0	0
	8	0	0	0	4.4	24.9	11.3	1.2	0	0	0	13.2
	9	3.8	0	0	3.3	2.8	0	0	0	0	19.8	0
	10	0	0	0	31.2	5.3	0	0	0	0	7.8	0
	11	0	1.8	5	11.3	45	0	0	0	0	2.5	11.2
	12	21.6	0	24.9	12.6	51.4	0	0	0	0.3	0	0
	13	0	0	2.6	0	5.1	0	0	0	0	0	3.7
	14	0	0	0	0.7	4.3	0	0	0	0	0	3.7
	15	0	0	6.2	12.3	0	0	0.2	0	0	0	12.2
	16	0	0	11.3	10.5	0	0	0	0	2.7	0	8.3
	17	0	6.3	7.6	11.8	0	18.2	0	0	0.1	0	0
	18	0	3.5	6.4	3.8	5.6	15.6	3.8	4	0	0	2.9
	19	0	15.8	0	5.7	9.3	6.8	0	0	0.4	0	30.5
	20	0	12.4	0	24.5	59.8	0	0	5.5	1.7	2.5	6.4
	21	0	1.1	0	0	36.3	3.3	0	0	0	0.5	0
	22	1.1	37.8	7.3	0.4	0.4	0	0	0	0	4.4	0
	23	0	11.3	0	5.6	4.3	5.9	3.4	0	0	0	0.9
	24	0.2	0.7	0	4.8	0	9.7	0.3	0	0	0	0
	25	84.8	1.1	6.5	12.5	1	2.9	5.5	1.7	0	0	0
	26	2.1	0	0.6	19.8	2.9	0	0	4.4	1.7	0	3.2
	27	0	0.3	6.8	33.2	5.3	0	0	0	0	0	0
	28	0	0	1.9	0.6	0	0	0	0	0	0	0.9
	29	0	0	37.8	9.3	0	0	0	4.5	0	0	0.5
	30	0	0	6	0.3	0	0	0	0	0	0	0.3
	31	0	0	0	0	1.5	0	0	0	1.7	0	0
2006	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	1	0	0	12.8	0	30	0	0	0.4	0	0	2.5
	2	0	0	0	0	3.4	17.8	0	0	2.8	0	11.5
	3	0	0	33.5	0	20.6	34.9	0	6.8	0	0	20
	4	0	0	0	0	8	2.2	0	16.6	1.4	4.4	27.4
	5	0	0	0	37.7	0.2	5.4	0	0.2	0	0	28.9
	6	0	0	0.1	7.5	0.5	30	0	0	0	0	0
	7	0	0.7	0	13.1	6.7	0.5	0	0	0	0	9.7
	8	0	0	0	11.6	2.3	1.2	0	0	0	0	17.8
	9	0	0	0	6.5	0	0	0	0	0	0	0
	10	0	0	0	8.4	6	0	0	0	1.4	0	0.2
	11	0	0	0	2.8	8.2	0	0	0.3	1.8	0	4.3
	12	0	0	0	66.3	0	3.1	0	7.8	4.8	0	43.8
	13	0	0	5	14.5	0	2	0	0	0	1.4	30.5
	14	0	0	0.3	2.1	0	0	0	20.4	0	0	31.5
	15	0	0	0	0	7.8	11.2	0	2.2	0	0	30.8
	16	0	0	0.3	0	0	68.6	0	0.4	0.7	0.5	1.6
	17	0	0	40.5	0	0	21.1	0.5	0	0	0	6.9
	18	0	0	0.7	0	0	0.5	0	2.7	1.3	0	10.5
	19	0	0	0.7	12.8	0	0	0.6	0	0	0	8.9
	20	0	0	0	59.3	0	8	0	0	0	0	15.7
	21	0	0	0	0.8	0	3.4	1.4	0	0	0	4.6
	22	1	0	8.2	7	0	8.8	8.4	0.4	0	0	24.3
	23	0	0	0	11.6	0	0	6.5	0	0	0	0
	24	0	0	21.9	9	0	2	0	1.3	1	0	36
	25	0	0	2.8	14	0	0	0	1.9	0.8	1	0
	26	0	0	33.3	5.8	0	0	0	0	1.5	0	0.3
	27	0	0	7.6	8.7	0	0	4.6	3.5	0.8	0	6.8
	28	0	0	0	37.9	0	0	4.7	0	0	0	30.1
	29	0	0	0	5.4	0	0	66.5	10.2	0	0	46.8
	30	0	0	0.1	0	0	0	35.6	0	0	0	0
	31	0	0	0	0.9	6.6	12.1	1.5	1.9	2.4	0	3.1

Appendix C-1 Flow discharge (m3/s)

Month	discharge m3/s	Month	discharge m3/s	Month	discharge m3/s	Month	discharge m3/s	Month	discharge m3/s	Month	discharge m3/s
Jan-00	0.052	Jan-01	0.049	Jan-02	0.035	Jan-03	0.093	Jan-04	0.046	Jan-05	0.059
Feb-00	0.045	Feb-01	0.043	Feb-02	0.037	Feb-03	0.102	Feb-04	0.056	Feb-05	0.052
Mar-00	0.044	Mar-01	0.039	Mar-02	0.036	Mar-03	0.076	Mar-04	0.086	Mar-05	0.049
Apr-00	0.052	Apr-01	0.045	Apr-02	0.074	Apr-03	0.082	Apr-04	0.093	Apr-05	0.076
May-00	0.07	May-01	0.084	May-02	0.078	May-03	1.213	May-04	0.096	May-05	0.078
Jun-00	0.074	Jun-01	0.082	Jun-02	0.081	Jun-03	0.102	Jun-04	0.080	Jun-05	0.091
Jul-00	0.065	Jul-01	0.061	Jul-02	0.07	Jul-03	0.076	Jul-04	0.080	Jul-05	0.072
Aug-00	0.055	Aug-01	0.054	Aug-02	0.068	Aug-03	0.066	Aug-04	0.063	Aug-05	0.074
Sep-00	0.043	Sep-01	0.047	Sep-02	0.062	Sep-03	0.076	Sep-04	0.054	Sep-05	0.061
Oct-00	0.044	Oct-01	0.036	Oct-02	0.059	Oct-03	0.056	Oct-04	0.036	Oct-05	0.052
Nov-00	0.044	Nov-01	0.0347	Nov-02	0.078	Nov-03	0.066	Nov-04	0.044	Nov-05	0.051
Dec-00	0.052	Dec-01	0.035	Dec-02	0.07	Dec-03	0.082	Dec-04	0.062	Dec-05	0.051