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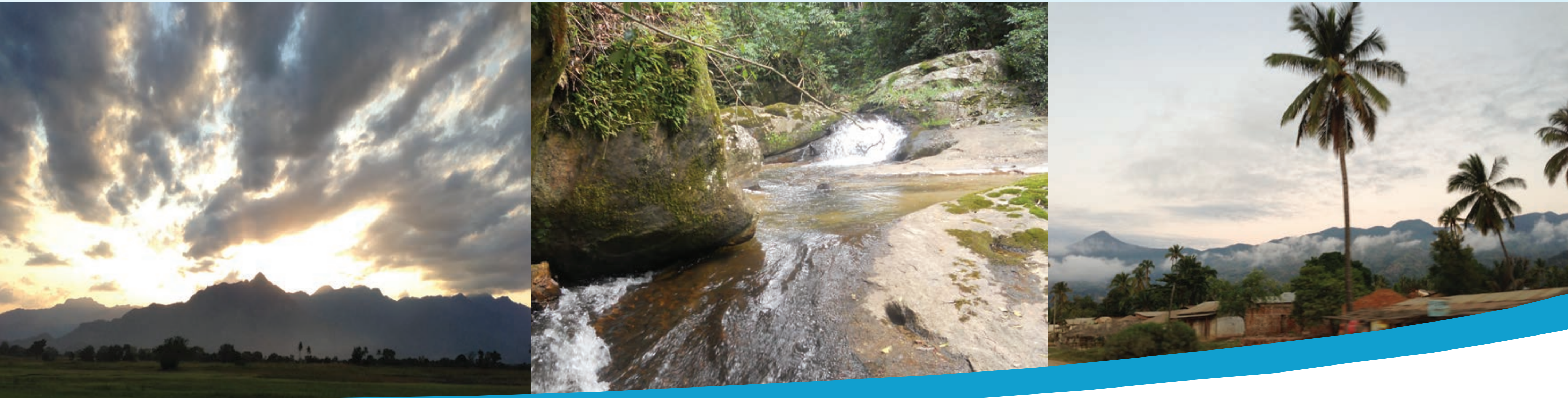
WATER ATLAS
of the Wami/Ruvu Basin
TANZANIA



WAMI/RUVU BASIN WATER OFFICE
WRBWO
MOROGORO

Tanzania Integrated Water, Sanitation and Hygiene Programme (iWASH)

FIU
Florida International University
Miami's public research university

WATER ATLAS
of the Wami/Ruvu Basin
TANZANIA

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Sources of Data:
The Wami/Ruvu Basin Water Office (Morogoro), Ministry of Water, Tanzania, provided data on rainfall, river discharge, water level, geology, hydrogeology, administration, infrastructure and population demographics. Data was obtained from the Wami/Ruvu Basin Water Resources Management and Development Study carried out by JICA and made available through the Wami/Ruvu Basin Water Office.

ClimateWizard has provided map layers for climate predictions (temperature, precipitation and evapotranspiration) run for the Wami/Ruvu basin based upon a basin boundary shapefile uploaded to the web interface (http://www.climatewizard.org)

1 km resolution Evapotranspiration raster datasets for the region were obtained from the NASA MODIS Global Evapotranspiration Project run by the Numerical Terradynamics Simulation Group at the University of Montana. (http://www.ntsg.umt.edu/project/mod16#data-product).

Digital Elevation Model (30m resolution, ASTER DEM) was obtained from NASA and Japan Space Research Organization.

Landsat images of the Wami/Ruvu basin region from 1984-2012 were obtained from Time and Google Earth via the online interface (http://world.time.com/timelapse/).

Forest cover change (2000-2012) images based on Landsat image analysis were obtained from Google Earth Engine and Hansen et al. 2013 via the web interface (http://www.earthenginepartners.appspot.com/science-2013-global-forest). Source: Hansen/UMD/Google/USGS/NASA

Data of threatened amphibian, reptile and mammal species were obtained from the IUCN web interface (http://www.iucnredlist.org/)

Rivers of the Wami/Ruvu Basin were digitized from Google Earth 2013.

All maps have been created using ArcGIS 10.2 unless specified otherwise.

Design: Alejandro Abramovich

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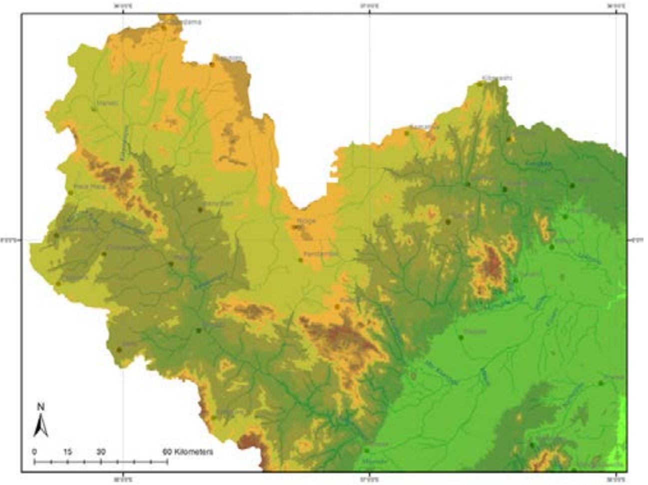
Foreword: a picture is worth a thousand words...

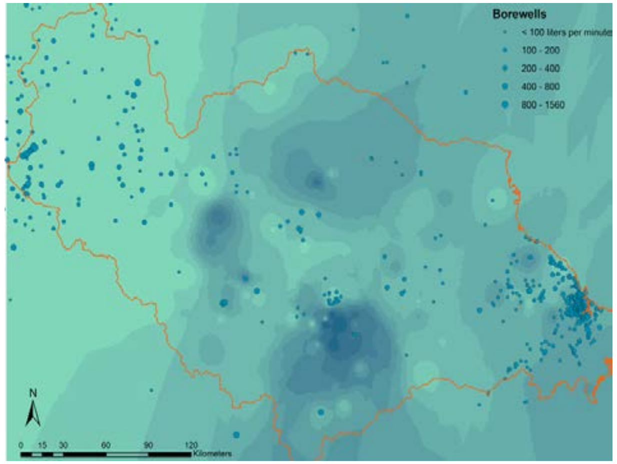
The role of spatial information in water resources management

Water resources management requires linking together hydrological, ecological, socioeconomic and water demand information, all of which are spatial by nature. For example there are high rainfall areas and arid zones, rainforests and deserts, agriculture and urban areas, high population density and water demand, and so on. Displaying these different sets of information on maps enables the viewer to observe patterns and connections existing between them and thereby understand the information better. The ability to view information spatially using maps thus enables the accurate assessment, planning, presentation and sustainable management of water. As an illustration of different thematic maps, the panel below displays three maps. On the left is a classic map of the landscape: topography, elevation and river networks give a two-dimensional sense of the physical features of a region. The middle map displays the spatial concentrations of groundwater borewells against a map of annual rainfall. Notice the clustering of borewells on the left and right sides of the map, corresponding to an arid area (hence high groundwater use) and urban area. Such a map can indicate the need to regulate the number of borewells and daily amount of groundwater extraction for sustainable groundwater use. The map on the right shows population density at the ward level, which provides an idea of domestic water demand.

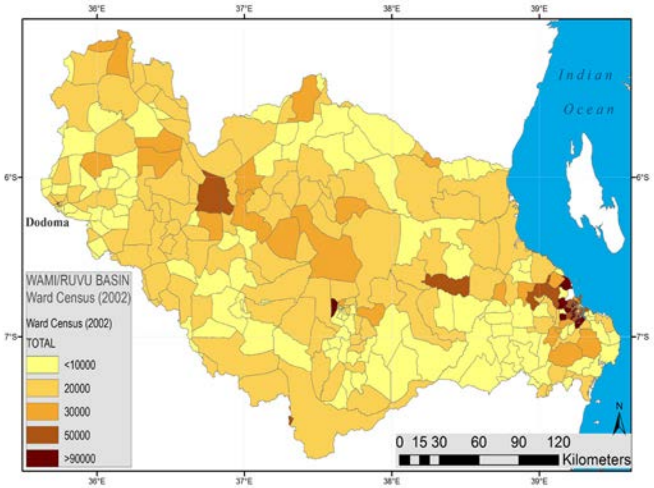
Yet another example is shown on the facing page. Plots of monthly river discharge in tributaries of the Ruvu river show the seasonal variability at each site, across the basin as well as the range of flow magnitudes across the basin. Such a map of hydrographs is useful to compare the discharge in different tributaries and locations in the river basin. For instance the headwaters of the Ruvu basin (left side of the map) have discharge ranging from 0.5—12 m3/s. Flow increases downstream until the last station, 1H8A shows discharge between 40 –150 m3/s. Such a map also indicates seasonal patterns of flow. The highest flow is seen to occur during the main rainy season between March and May. Headwater rivers have the highest flow in March-April, whereas stations downstream see a lag of around 1 month in peak discharge. By placing hydrographs on a river basin map thus help visualize the flow across an entire river basin.



Topography and rivers of western Wami Basin.



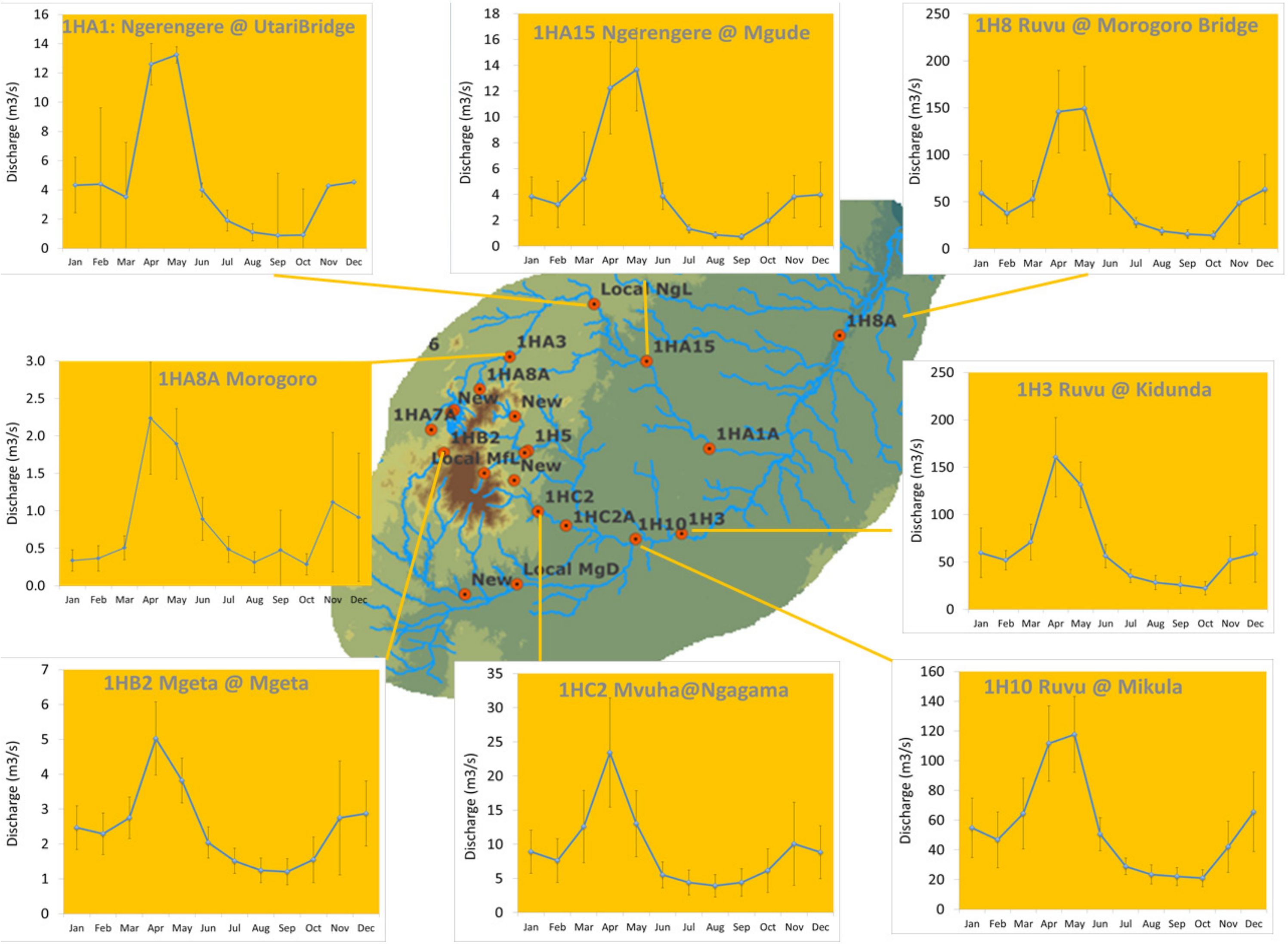
Borewells and annual average rainfall in the Wami/Ruvu Basin.



Population in wards of the Wami/Ruvu Basin.

Objectives of this Atlas

To present information that aids understanding the spatial patterns of water supply, water demand and use in the Wami/Ruvu Basin. Bringing together different aspects of water availability and use on a single map allows for noting spatial patterns that are otherwise hidden in data sets.
This Atlas can also be used in conjunction with the **Digital Atlas of Water Resources** of the Wami/Ruvu Basin, which allows users to zoom into any area of a map, as well as access additional information by clicking on features. The Digital Atlas can be accessed at http://glows/fiu.edu



Using the Water Atlas

Information in the Atlas has been organized into the broad themes of

- Landscape/climate/geology
- Water resources
- Water use and demand.
- Vulnerability

Information is presented along the pathway of a drop of water, from rainfall and climate to the landscape, factors that affect the flow and retention of water on the landscape, on to abstraction, use and demand of water. Finally the vulnerability of water resources in the entire basin and directions for adaptive strategies are presented.

Hydrographs or monthly discharge plots (averaged over 1950-2010) for various tributaries and locations in the Ruvu river system.

Section 1:

The Wami/Ruvu Basin at a glance

1.1 Introduction

The Wami and Ruvu rivers arise in the Eastern Arc mountain range in central Tanzania, and flow eastwards through some of the country's major agricultural, industrial and urban areas before discharging into the Indian Ocean north of the historic port of Bagamoyo. The large urban centres of Dar Es Salaam, Morogoro, and Dodoma, all fall in the catchment area of the Wami and Ruvu rivers. A large climatic diversity exists within the basins, from the humid plains along the Indian Ocean coastline, to the Eastern Arcs Mountains with high rainfall, and arid areas around Dodoma further west, that lie in the rain shadow of the mountains. Climate and biogeographic history has resulted in a stunningly large variety of biodiversity-rich ecosystems, notably the montane forests, in the Eastern Arc Mountains, the savanna woodlands famous worldwide for wildlife, and coastal mangroves, seagrass beds and coral reefs that form nurseries for marine fish. A wide range of livelihoods exist in the Wami and Ruvu basins encompassing rain-fed and irrigated agriculture, livestock, forest produce and leading industries of Tanzania. Such a diversity of water availability and increasing demands present within the basin poses an ever-widening challenge of sustainable water resources management. How this challenge is starting to be addressed with the involvement of all stakeholders in the basins, from village communities and schools to large water users and the Ministry of Water, can form a model for other regions of Tanzania, East Africa, and developing nations worldwide. The Water Atlas hopes to assist in this endeavor, by presenting a set of up-to-date maps visualizing various aspects of water resource availability and demand in the Wami/Ruvu Basin. Water resources in the Wami River Basin, Ruvu River Basin and Coastal Rivers Basin are managed by the Wami/Ruvu Basin Water Board of the Ministry of Water.

1.2 Vulnerability of water resources in the Wami/Ruvu Basin

Increasing water demand

in all sectors from a growing population, industrial growth, increase in irrigated agriculture, increasing per-capita consumption of goods and services that utilize water.

Increasing pollution

of water from soil erosion, sewage, industries, agrochemicals and stormwater runoff laden with oil, grease and plastic garbage.

Decreasing landscape capacity

to regulate water quality and availability: Land Cover and Land Use Change—deforestation, wetland loss, desertification in arid areas.

Climate change:

Increasing uncertainty of rainfall onset, duration, distribution and amount; rise in temperatures; sea level rise and coastal groundwater salinity.

1.3 Main Water Needs in the Wami and Ruvu basin

- **ECOSYSTEMS**
- **AGRICULTURE**
- **DOMESTIC (rural and urban)**
- **ENERGY**
- **INDUSTRY/COMMERCIAL**
- **LIVESTOCK**

Ecosystems: vegetation and wildlife are adapted to naturally occurring rainfall and water availability; changes to water availability, such as the over-extraction of water from rivers can harm ecosystems.

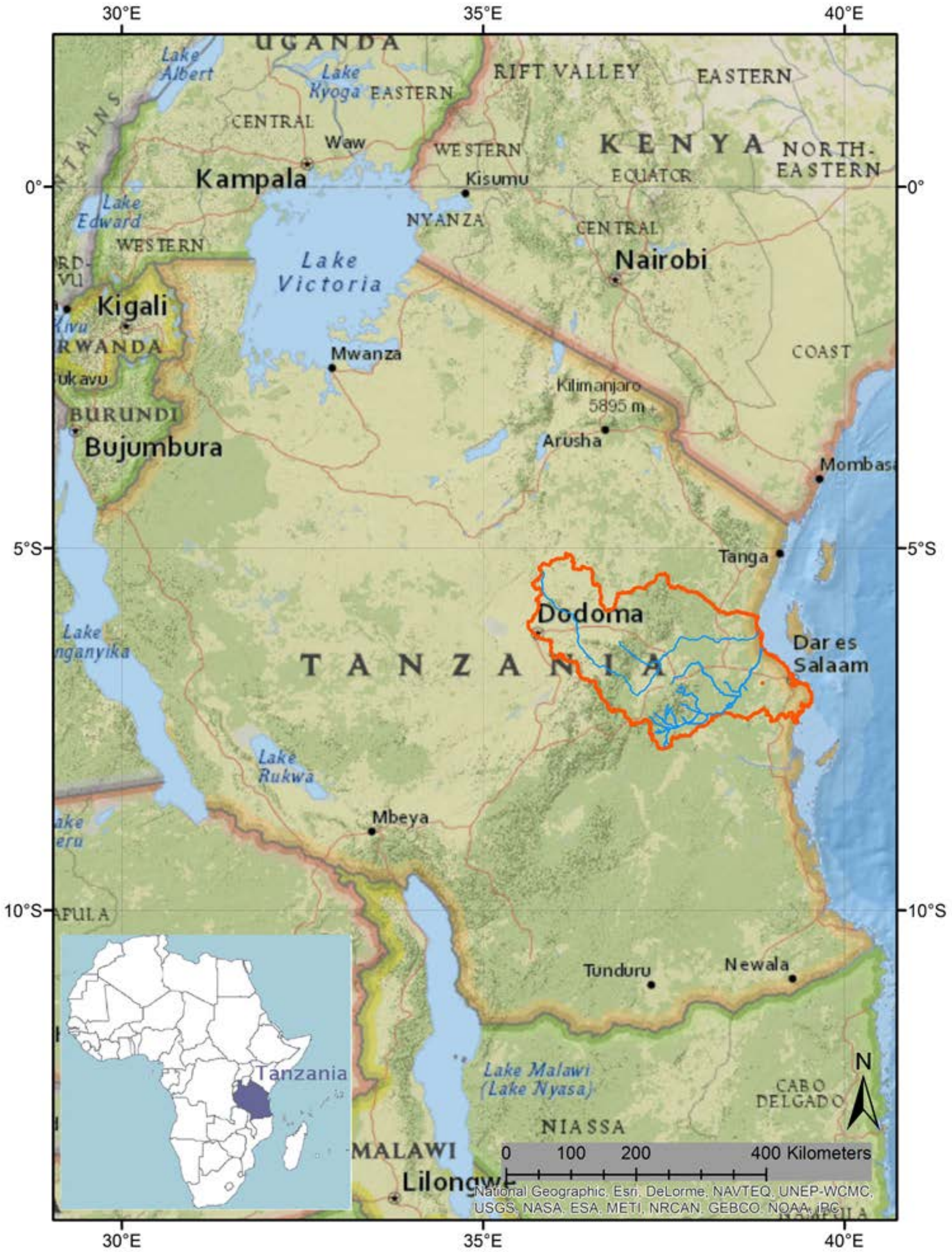
Agriculture includes both rainfed and irrigated farms and is the largest water user in the Basin.

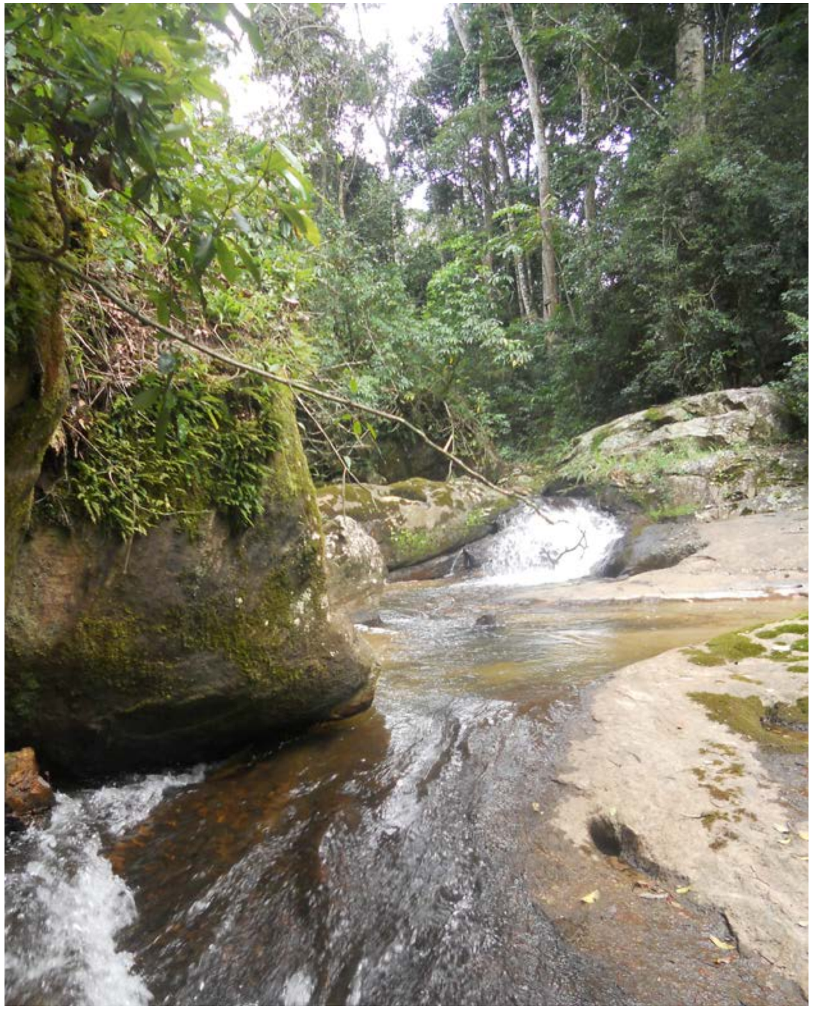
Domestic rural consumption includes use of water for drinking, cooking, washing and kitchen gardens.

Industry has various water needs, as well as need effective treatment plants.

Livestock historically had access to rivers for drinking; however expanding farmland in some cases cuts off access to streams which may lead to pastoralist-farmer conflicts.

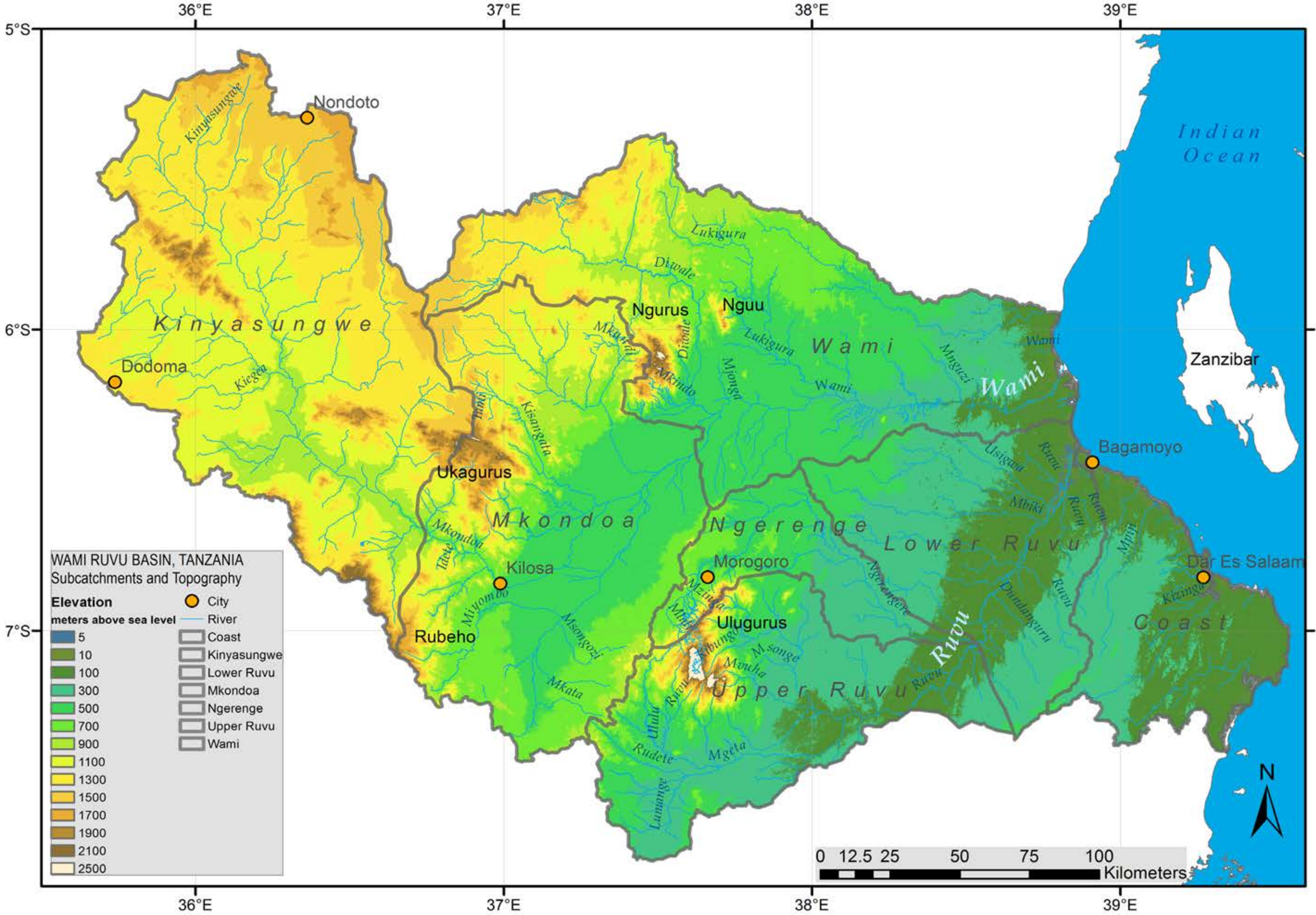
Map_1_1: Location of the Wami/Ruvu Basin in Tanzania, Africa



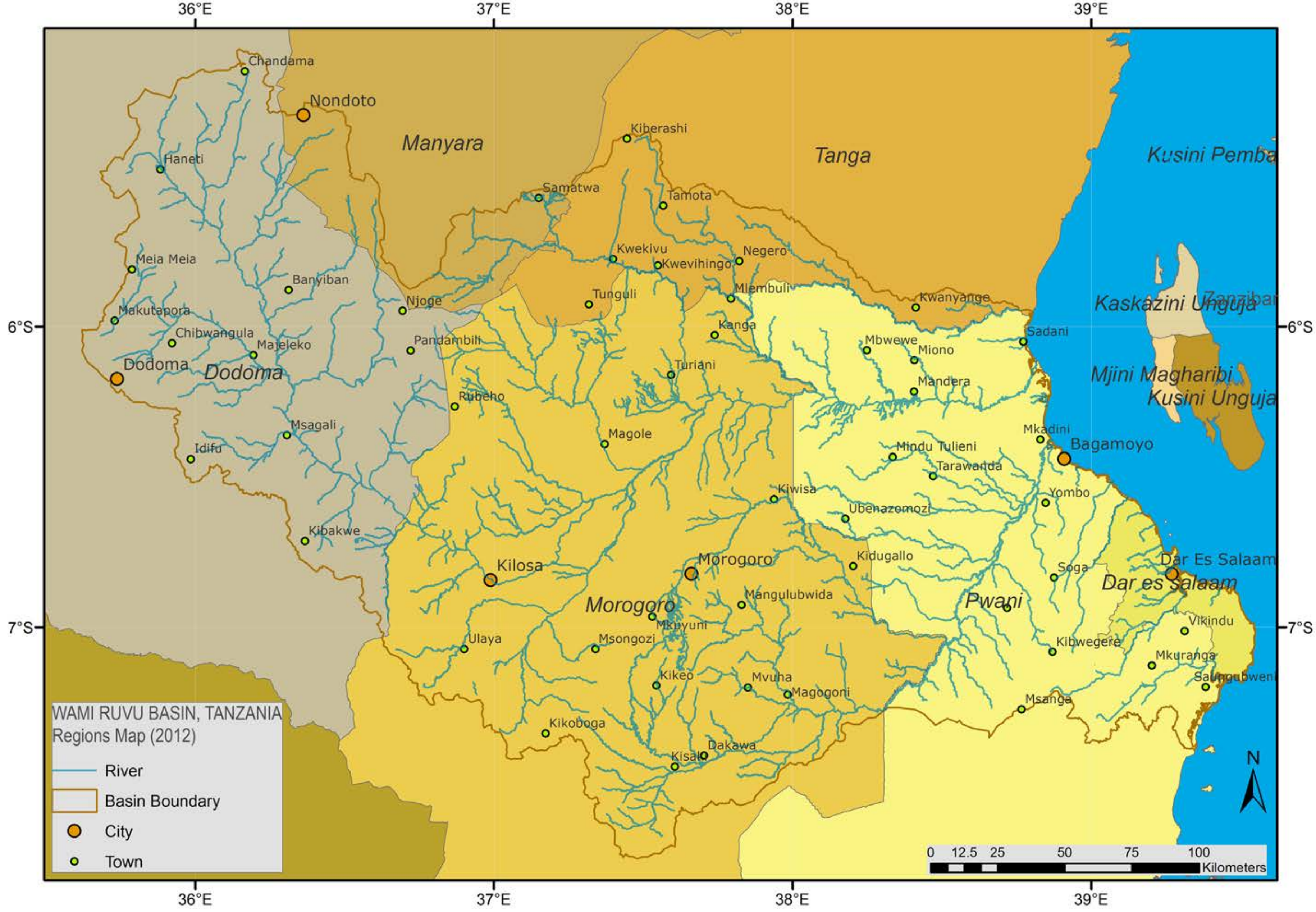


Headwaters of the Mkindo tributary of the Wami river in the Nguru mountains, part of the perpetually cloudy, biodiversity-rich Eastern Arc mountain range in Kenya and Tanzania that constitutes headwater catchments for many rivers in the region.

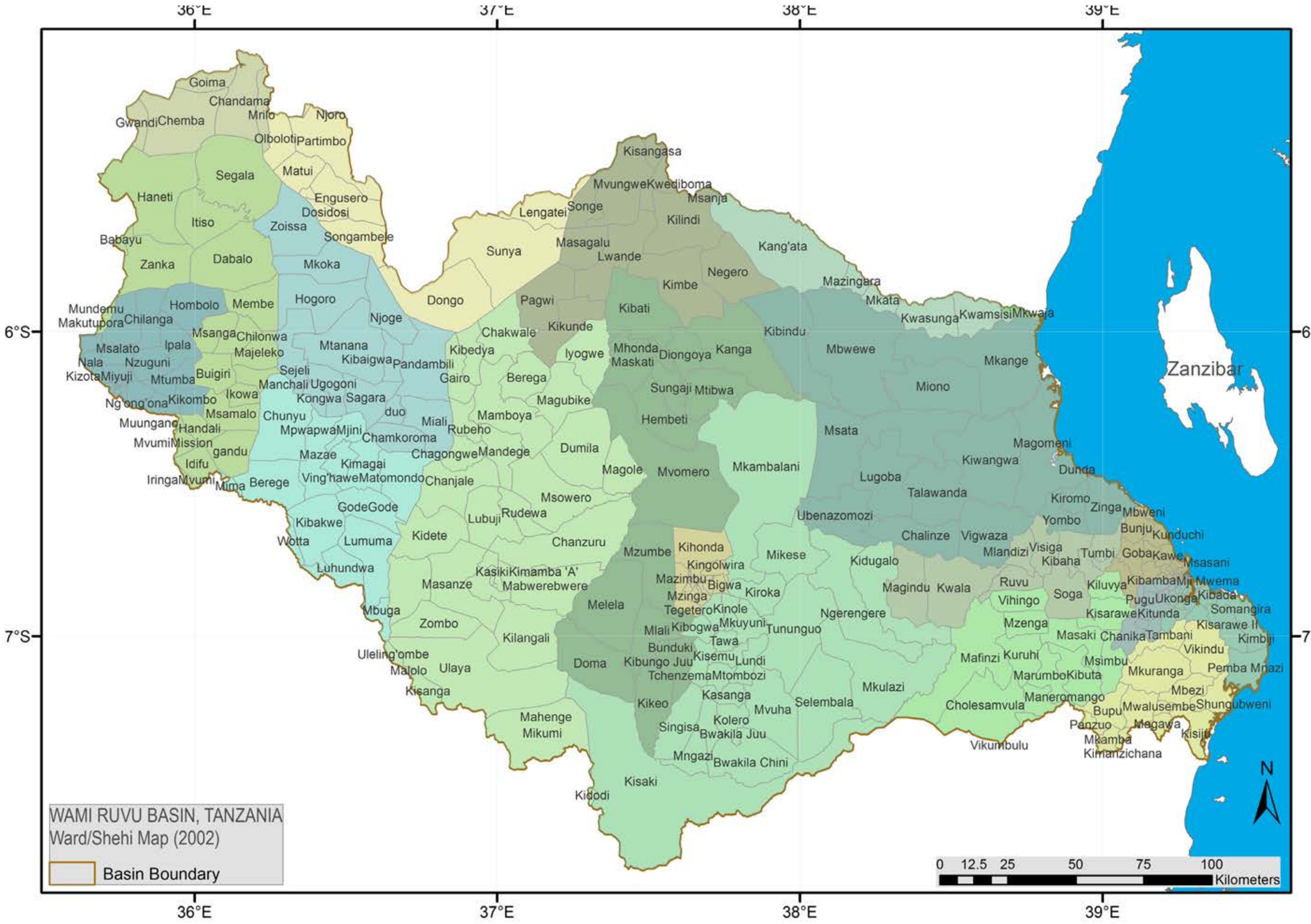
Map_1_2: Topography, subcatchments and cities



Map_1_3: Administrative regions, cities and towns

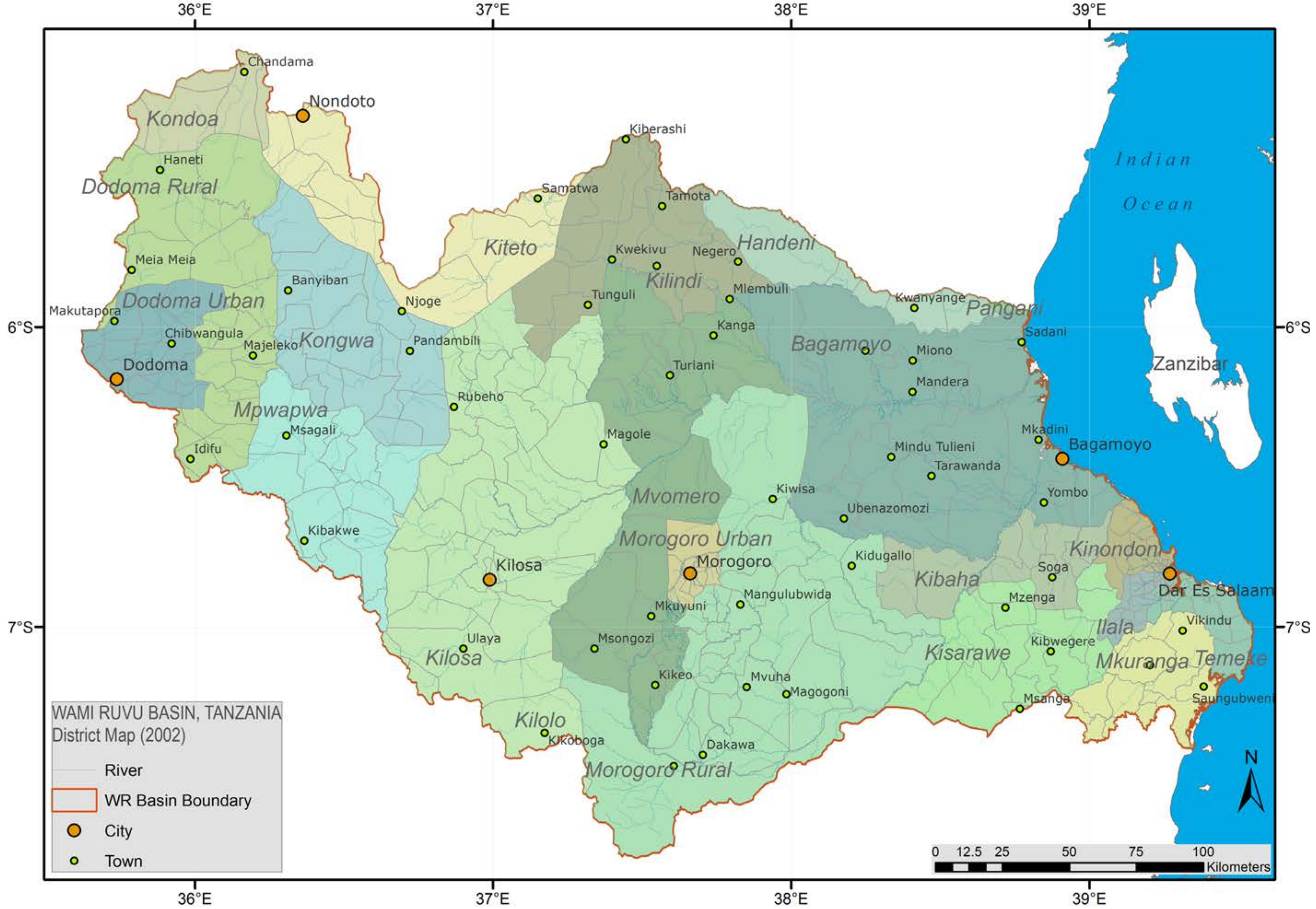


Map_1_4: District wards (2002 Census)

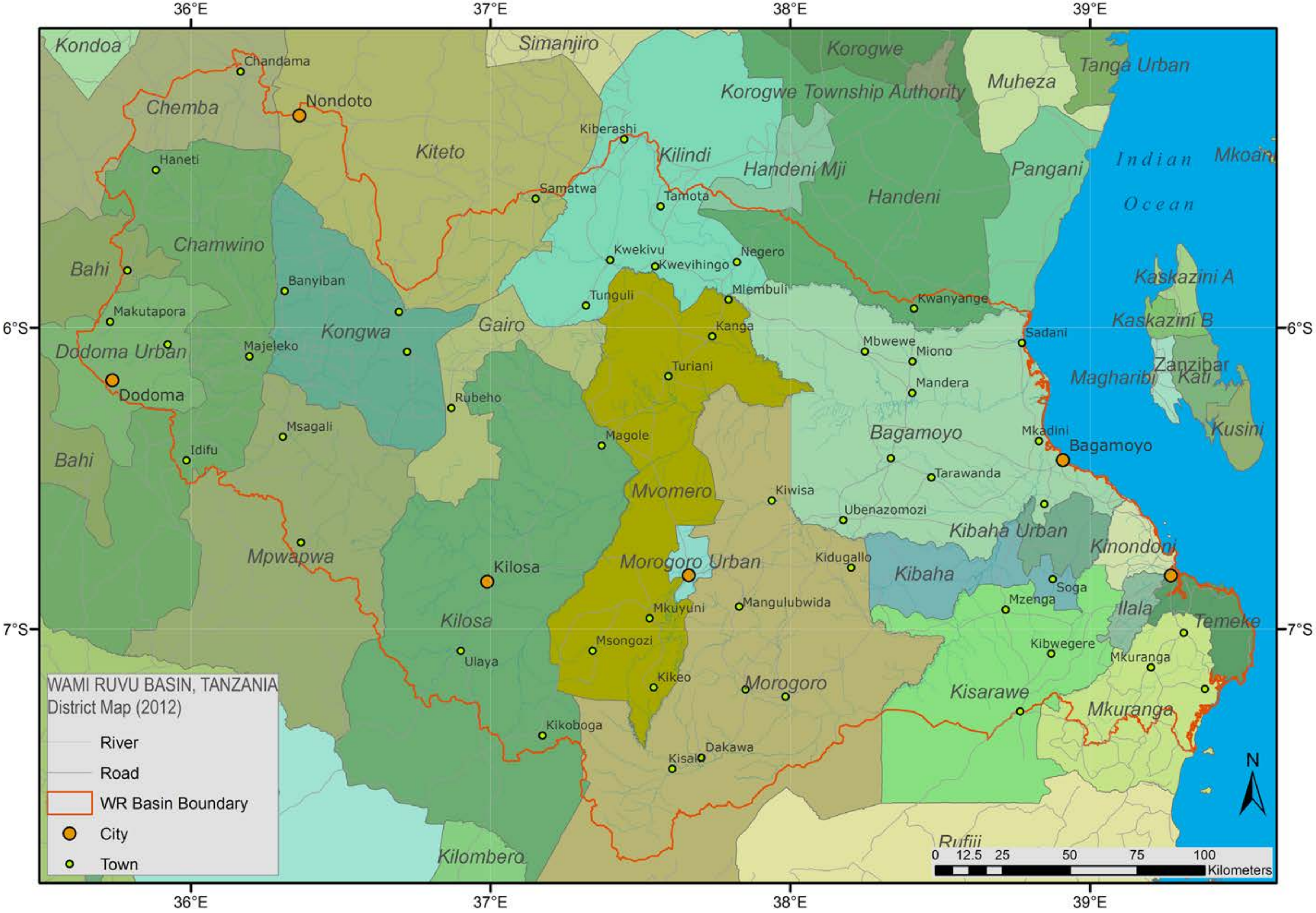


Ward boundaries have changed and new wards created between 2002-2012. However at the time of developing this Atlas, maps of the new wards have not yet become available.

Map_1_5_A : Districts (2002 Census)

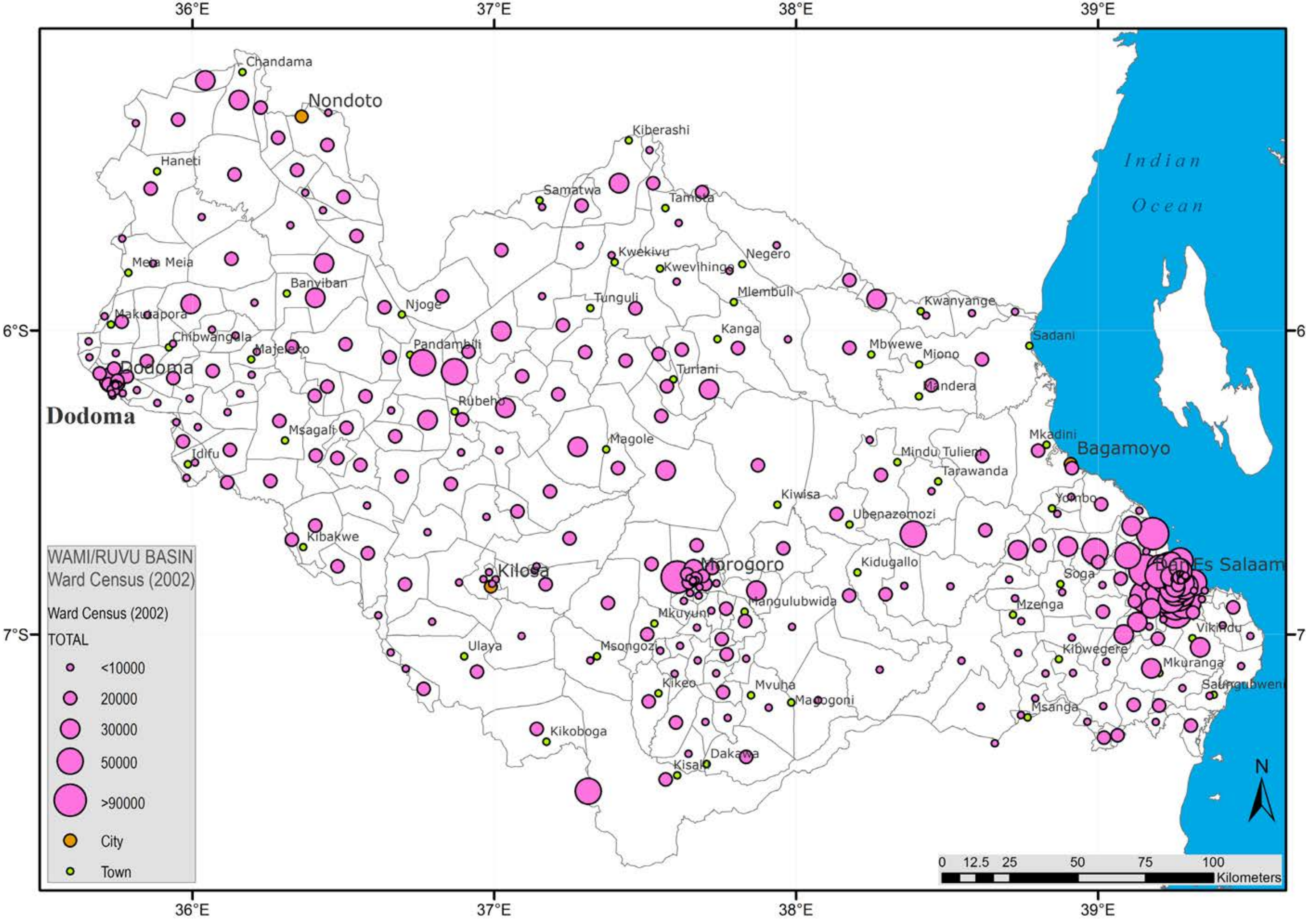


Map_1_5_B : Districts (2012 Census)



Note: There have been changes in districts over 2002-2012; for instance, the area formerly under Dodoma Rural has been divided into Bahi, Chamwino and Chemba.

Map_1_6 : Population of wards (2002 Census)



Map_1_7 : Population density at the ward level (2002 census)

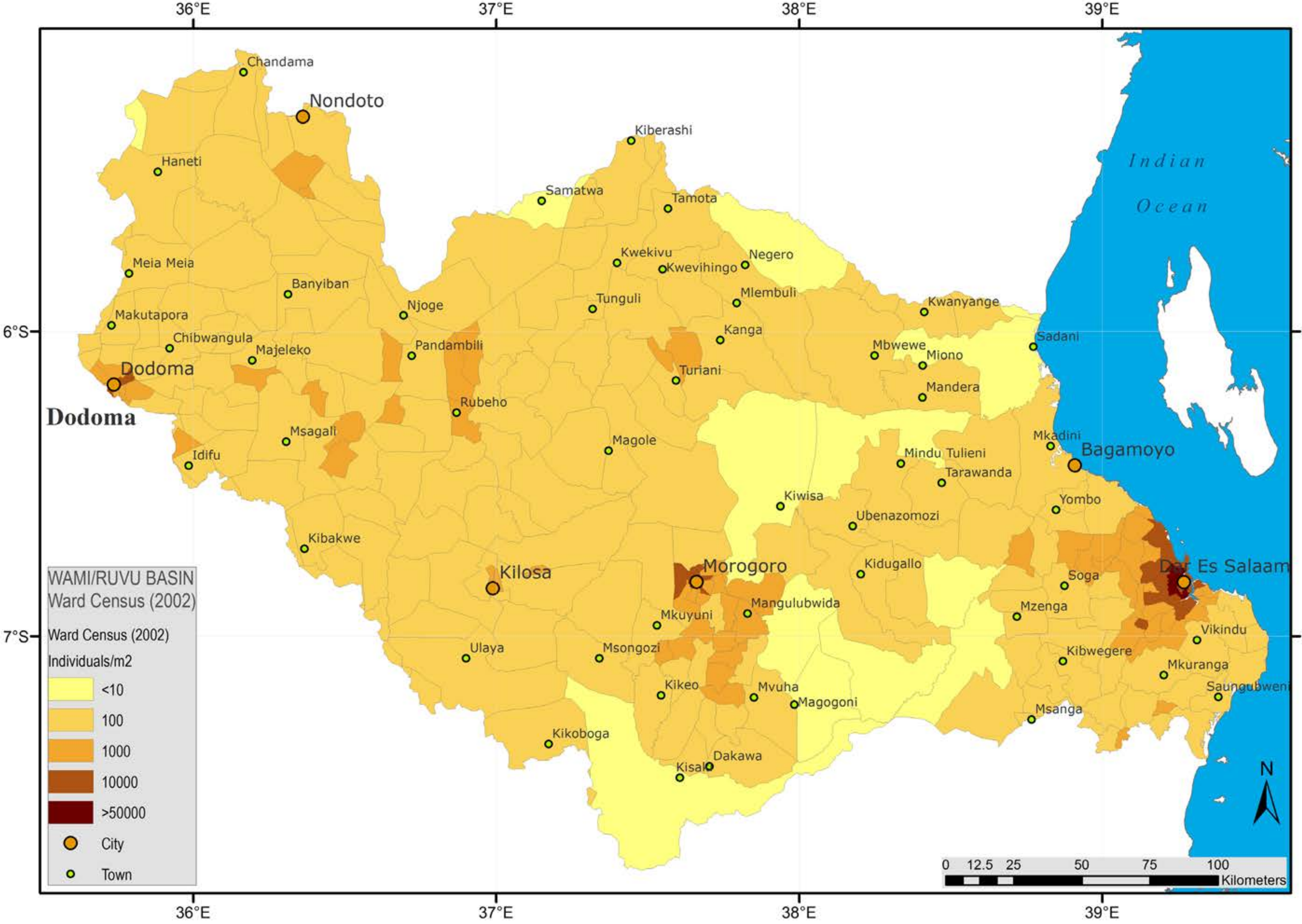
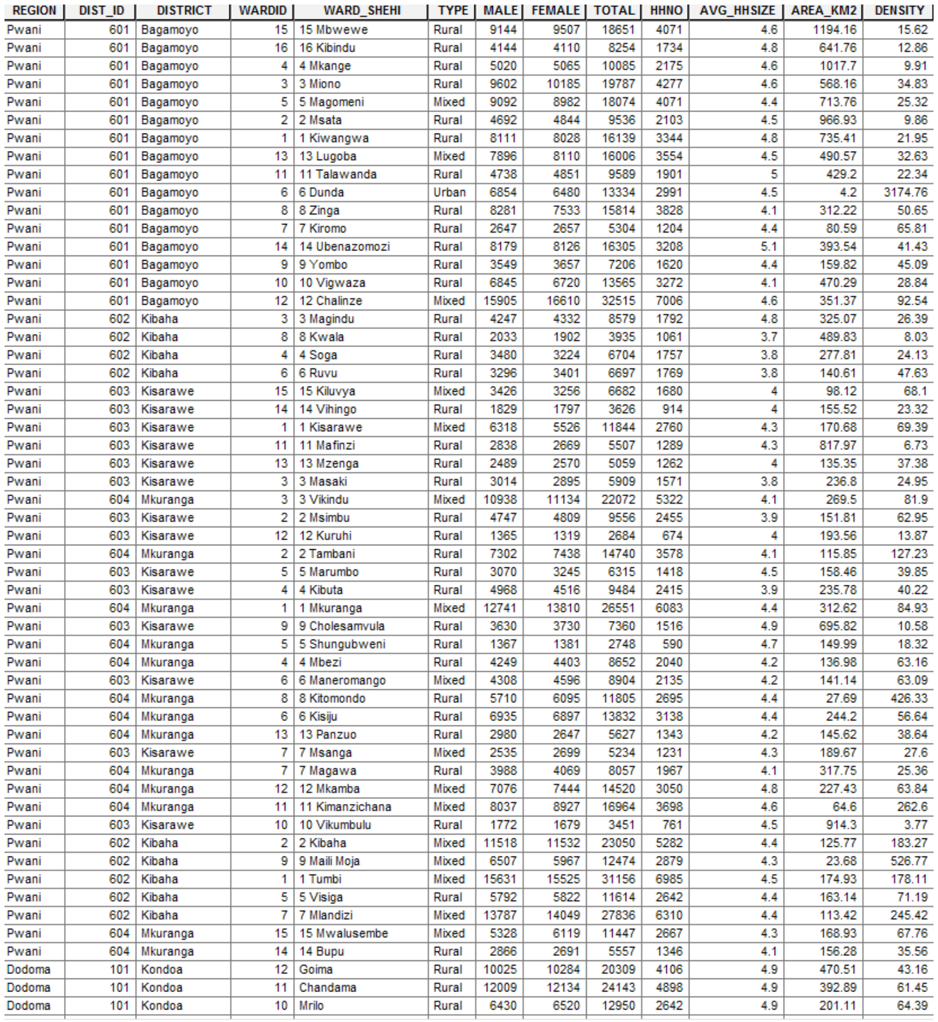
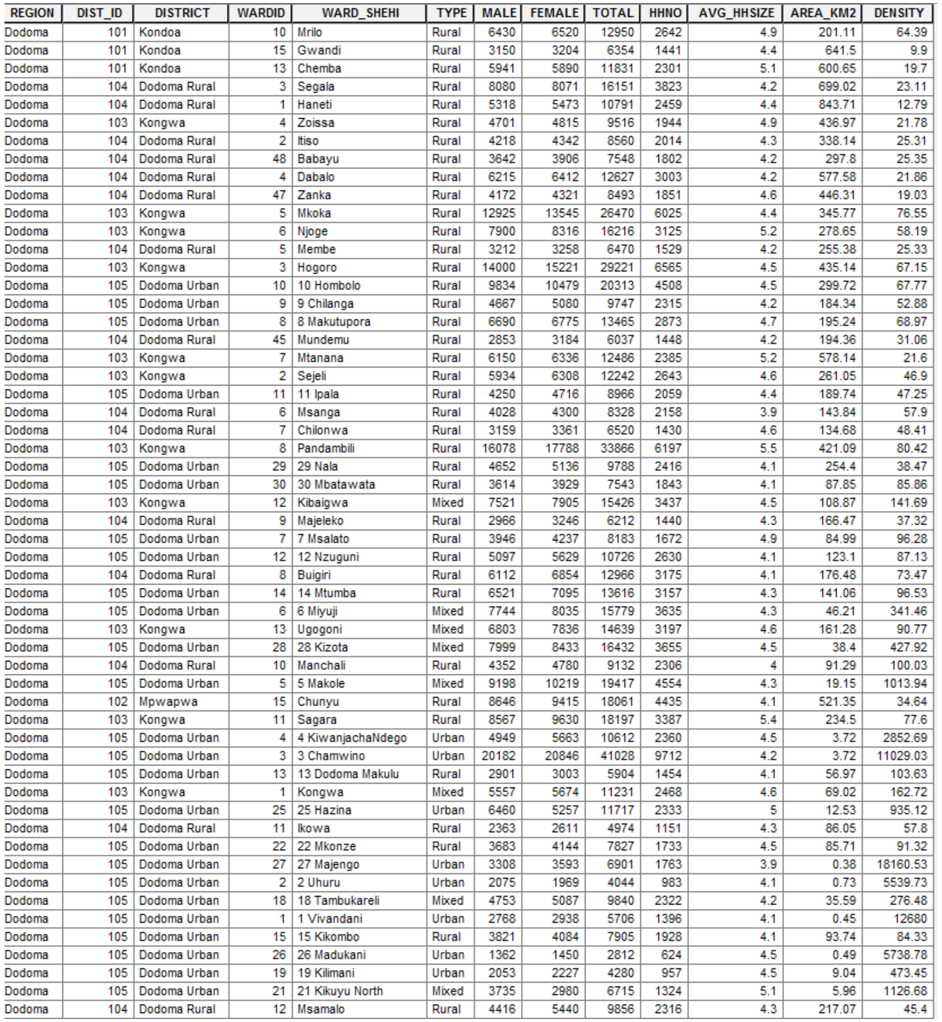


Plate_1_1 : Population demographics in the Wami/Ruvu Basin (2002 Census)

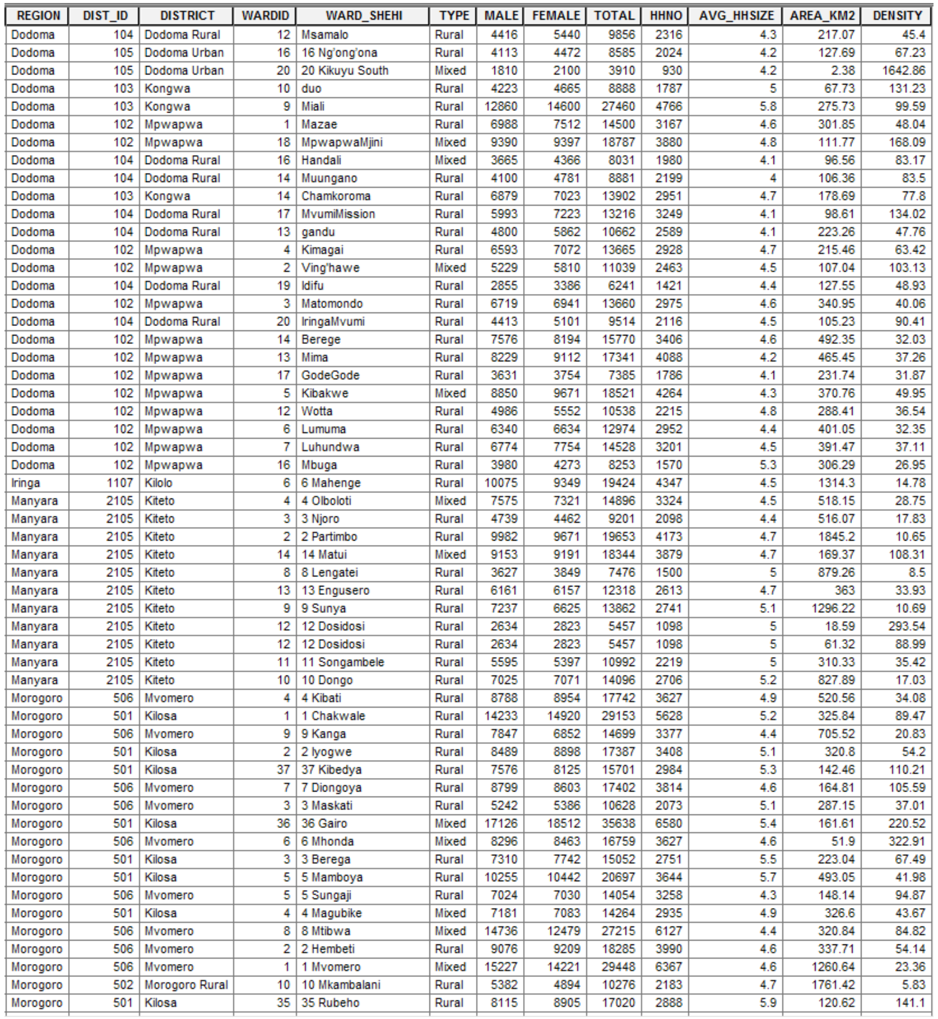


REGION	DIST_ID	DISTRICT	WARDID	WARD_SHEHI	TYPE	MALE	FEMALE	TOTAL	HHNO	AVG_HHSIZE	AREA_KM2	DENSITY
Pwani	601	Bagamoyo	15	15 Mbwewe	Rural	9144	9507	18651	4071	4.6	1194.16	15.62
Pwani	601	Bagamoyo	16	16 Kibindu	Rural	4144	4110	8254	1734	4.8	641.76	12.86
Pwani	601	Bagamoyo	4	4 Mkange	Rural	5020	5065	10085	2175	4.6	1017.7	9.91
Pwani	601	Bagamoyo	3	3 Miono	Rural	9602	10185	19787	4277	4.6	568.16	34.83
Pwani	601	Bagamoyo	5	5 Magomeni	Mixed	9092	8982	18074	4071	4.4	713.76	25.32
Pwani	601	Bagamoyo	2	2 Msata	Rural	4692	4844	9536	2103	4.5	966.93	9.86
Pwani	601	Bagamoyo	1	1 Kiwangwa	Rural	8111	8028	16139	3344	4.8	735.41	21.95
Pwani	601	Bagamoyo	13	13 Lugoba	Mixed	7896	8110	16006	3554	4.5	490.57	32.63
Pwani	601	Bagamoyo	11	11 Talawanda	Rural	4738	4851	9589	1901	5	429.2	22.34
Pwani	601	Bagamoyo	6	6 Dunda	Urban	6854	6480	13334	2991	4.5	4.2	3174.76
Pwani	601	Bagamoyo	8	8 Zinga	Rural	8281	7533	15814	3828	4.1	312.22	50.65
Pwani	601	Bagamoyo	7	7 Kiromo	Rural	2647	2657	5304	1204	4.4	80.59	65.81
Pwani	601	Bagamoyo	14	14 Ubenazomozi	Rural	8179	8126	16305	3208	5.1	393.54	41.43
Pwani	601	Bagamoyo	9	9 Yombo	Rural	3549	3657	7206	1620	4.4	159.82	45.09
Pwani	601	Bagamoyo	10	10 Vigwaza	Rural	6845	6720	13565	3272	4.1	470.29	28.84
Pwani	601	Bagamoyo	12	12 Chalinze	Mixed	15905	16610	32515	7006	4.6	351.37	92.54
Pwani	602	Kibaha	3	3 Magindu	Rural	4247	4332	8579	1792	4.8	325.07	26.39
Pwani	602	Kibaha	8	8 Kwala	Rural	2033	1902	3935	1061	3.7	489.83	8.03
Pwani	602	Kibaha	4	4 Soga	Rural	3480	3224	6704	1757	3.8	277.81	24.13
Pwani	602	Kibaha	6	6 Ruvu	Rural	3296	3401	6697	1769	3.8	140.61	47.63
Pwani	603	Kisarawe	15	15 Kiluvya	Mixed	3426	3256	6682	1680	4	98.12	68.1
Pwani	603	Kisarawe	14	14 Vihingo	Rural	1829	1797	3626	914	4	155.52	23.32
Pwani	603	Kisarawe	1	1 Kisarawe	Mixed	6318	5526	11844	2760	4.3	170.68	69.39
Pwani	603	Kisarawe	11	11 Mafinzi	Rural	2838	2669	5507	1289	4.3	817.97	6.73
Pwani	603	Kisarawe	13	13 Mzenga	Rural	2489	2570	5059	1262	4	135.35	37.38
Pwani	603	Kisarawe	3	3 Masaki	Rural	3014	2895	5909	1571	3.8	236.8	24.95
Pwani	604	Mkuranga	3	3 Vikindu	Mixed	10938	11134	22072	5322	4.1	269.5	81.9
Pwani	603	Kisarawe	2	2 Msimbu	Rural	4747	4809	9556	2455	3.9	151.81	62.95
Pwani	603	Kisarawe	12	12 Kuruhi	Rural	1365	1319	2684	674	4	193.56	13.87
Pwani	604	Mkuranga	2	2 Tambani	Rural	7302	7438	14740	3578	4.1	115.85	127.23
Pwani	603	Kisarawe	5	5 Marumbo	Rural	3070	3245	6315	1418	4.5	158.46	39.85
Pwani	603	Kisarawe	4	4 Kibuta	Rural	4968	4516	9484	2415	3.9	235.78	40.22
Pwani	604	Mkuranga	1	1 Mkuranga	Mixed	12741	13810	26551	6083	4.4	312.62	84.93
Pwani	603	Kisarawe	9	9 Cholesamvula	Rural	3630	3730	7360	1516	4.9	695.82	10.58
Pwani	604	Mkuranga	5	5 Shungubweni	Rural	1367	1381	2748	590	4.7	149.99	18.32
Pwani	604	Mkuranga	4	4 Mbezi	Rural	4249	4403	8652	2040	4.2	136.98	63.16
Pwani	603	Kisarawe	6	6 Maneromango	Mixed	4308	4596	8904	2135	4.2	141.14	63.09
Pwani	604	Mkuranga	8	8 Kitomondo	Rural	5710	6095	11805	2695	4.4	27.69	426.33
Pwani	604	Mkuranga	6	6 Kisiju	Rural	6935	6897	13832	3138	4.4	244.2	56.64
Pwani	604	Mkuranga	13	13 Panzuo	Rural	2980	2647	5627	1343	4.2	145.62	38.64
Pwani	603	Kisarawe	7	7 Msanga	Mixed	2535	2699	5234	1231	4.3	189.67	27.6
Pwani	604	Mkuranga	7	7 Magawa	Rural	3988	4069	8057	1967	4.1	317.75	25.36
Pwani	604	Mkuranga	12	12 Mkamba	Mixed	7076	7444	14520	3050	4.8	227.43	63.84
Pwani	604	Mkuranga	11	11 Kimanzichana	Mixed	8037	8927	16964	3698	4.6	64.6	262.6
Pwani	603	Kisarawe	10	10 Vikumbulu	Rural	1772	1679	3451	761	4.5	914.3	3.77
Pwani	602	Kibaha	2	2 Kibaha	Mixed	11518	11532	23050	5282	4.4	125.77	183.27
Pwani	602	Kibaha	9	9 Maili Moja	Mixed	6507	5967	12474	2879	4.3	23.68	526.77
Pwani	602	Kibaha	1	1 Tumbi	Mixed	15631	15525	31156	6985	4.5	174.93	178.11
Pwani	602	Kibaha	5	5 Visiga	Rural	5792	5822	11614	2642	4.4	163.14	71.19
Pwani	602	Kibaha	7	7 Mlandizi	Mixed	13787	14049	27836	6310	4.4	113.42	245.42
Pwani	604	Mkuranga	15	15 Mwalusembe	Mixed	5328	6119	11447	2667	4.3	168.93	67.76
Pwani	604	Mkuranga	14	14 Bupu	Rural	2866	2691	5557	1346	4.1	156.28	35.56
Dodoma	101	Kondoa	12	Goima	Rural	10025	10284	20309	4106	4.9	470.51	43.16
Dodoma	101	Kondoa	11	Chandama	Rural	12009	12134	24143	4898	4.9	392.89	61.45
Dodoma	101	Kondoa	10	Mrilo	Rural	6430	6520	12950	2642	4.9	201.11	64.39

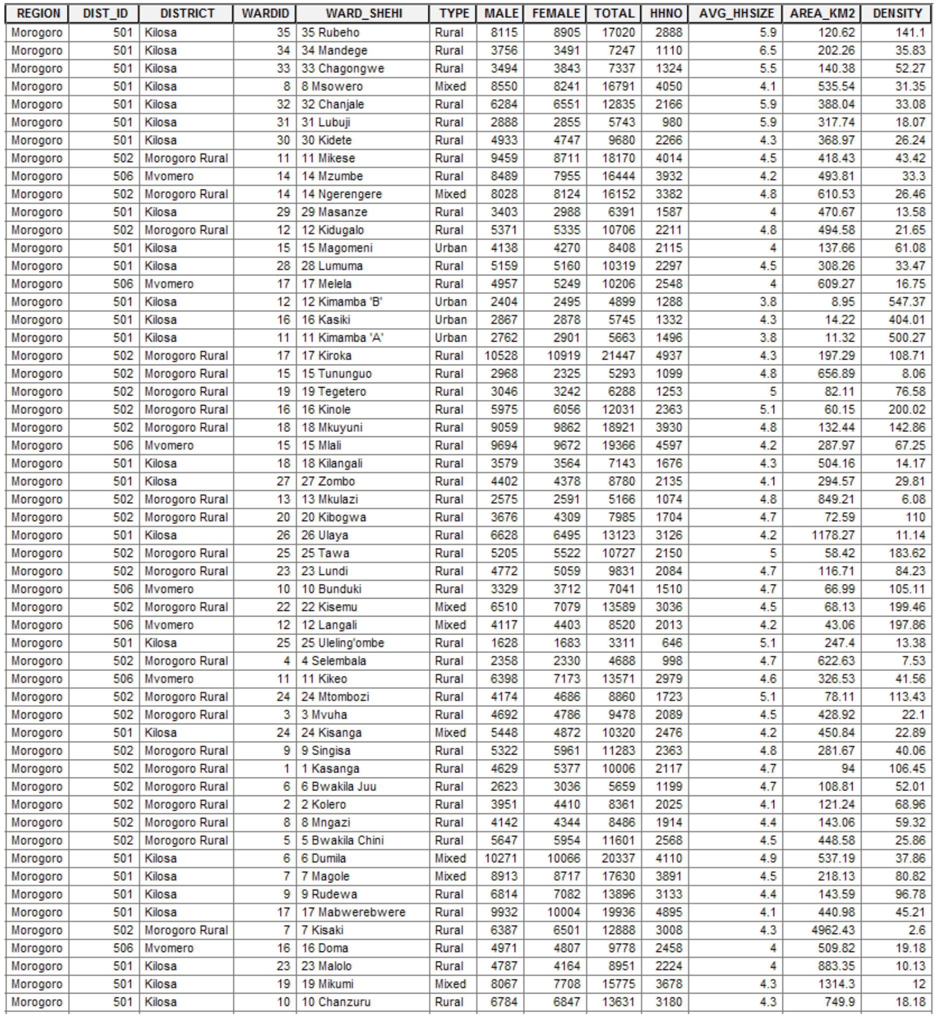


REGION	DIST_ID	DISTRICT	WARDID	WARD_SHEHI	TYPE	MALE	FEMALE	TOTAL	HHNO	AVG_HHSIZE	AREA_KM2	DENSITY
Dodoma	101	Kondoa	10	Mrilo	Rural	6430	6520	12950	2642	4.9	201.11	64.39
Dodoma	101	Kondoa	15	Gwandi	Rural	3150	3204	6354	1441	4.4	641.5	9.9
Dodoma	101	Kondoa	13	Chemba	Rural	5941	5890	11831	2301	5.1	600.65	19.7
Dodoma	104	Dodoma Rural	3	Segala	Rural	8080	8071	16151	3823	4.2	699.02	23.11
Dodoma	104	Dodoma Rural	1	Haneti	Rural	5318	5473	10791	2459	4.4	843.71	12.79
Dodoma	103	Kongwa	4	Zoissa	Rural	4701	4815	9516	1944	4.9	436.97	21.78
Dodoma	104	Dodoma Rural	2	Itiso	Rural	4218	4342	8560	2014	4.3	338.14	25.31
Dodoma	104	Dodoma Rural	48	Babayu	Rural	3642	3906	7548	1802	4.2	297.8	25.35
Dodoma	104	Dodoma Rural	4	Dabalo	Rural	6215	6412	12627	3003	4.2	577.58	21.86
Dodoma	104	Dodoma Rural	47	Zanka	Rural	4172	4321	8493	1851	4.6	446.31	19.03
Dodoma	103	Kongwa	5	Mkoka	Rural	12925	13545	26470	6025	4.4	345.77	76.55
Dodoma	103	Kongwa	6	Njoge	Rural	7900	8316	16216	3125	5.2	278.65	58.19
Dodoma	104	Dodoma Rural	5	Membe	Rural	3212	3258	6470	1529	4.2	255.38	25.33
Dodoma	103	Kongwa	3	Hogoro	Rural	14000	15221	29221	6565	4.5	435.14	67.15
Dodoma	105	Dodoma Urban	10	10 Hombolo	Rural	9834	10479	20313	4508	4.5	299.72	67.77
Dodoma	105	Dodoma Urban	9	9 Chilanga	Rural	4667	5080	9747	2315	4.2	184.34	52.88
Dodoma	105	Dodoma Urban	8	8 Makutupora	Rural	6690	6775	13465	2873	4.7	195.24	68.97
Dodoma	104	Dodoma Rural	45	Mundemu	Rural	2853	3184	6037	1448	4.2	194.36	31.06
Dodoma	103	Kongwa	7	Mtanana	Rural	6150	6336	12486	2385	5.2	578.14	21.6
Dodoma	103	Kongwa	2	Sejeli	Rural	5934	6308	12242	2643	4.6	261.05	46.9
Dodoma	105	Dodoma Urban	11	11 Ipala	Rural	4250	4716	8966	2059	4.4	189.74	47.25
Dodoma	104	Dodoma Rural	6	Msanga	Rural	4028	4300	8328	2158	3.9	143.84	57.9
Dodoma	104	Dodoma Rural	7	Chilonwa	Rural	3159	3361	6520	1430	4.6	134.68	48.41
Dodoma	103	Kongwa	8	Pandambili	Rural	16078	17788	33866	6197	5.5	421.09	80.42
Dodoma	105	Dodoma Urban	29	29 Nala	Rural	4652	5136	9788	2416	4.1	254.4	38.47
Dodoma	105	Dodoma Urban	30	30 Mbatawata	Rural	3614	3929	7543	1843	4.1	87.85	85.86
Dodoma	103	Kongwa	12	Kibaigwa	Mixed	7521	7905	15426	3437	4.5	108.87	141.69
Dodoma	104	Dodoma Rural	9	Majeleko	Rural	2966	3246	6212	1440	4.3	166.47	37.32
Dodoma	105	Dodoma Urban	7	7 Msalato	Rural	3946	4237	8183	1672	4.9	84.99	96.28
Dodoma	105	Dodoma Urban	12	12 Nzuguni	Rural	5097	5629	10726	2630	4.1	123.1	87.13
Dodoma	104	Dodoma Rural	8	Buigiri	Rural	6112	6854	12966	3175	4.1	176.48	73.47
Dodoma	105	Dodoma Urban	14	14 Mtumba	Rural	6521	7095	13616	3157	4.3	141.06	96.53
Dodoma	105	Dodoma Urban	6	6 Miyuji	Mixed	7744	8035	15779	3635	4.3	46.21	341.46
Dodoma	103	Kongwa	13	Ugogoni	Mixed	6803	7836	14639	3197	4.6	161.28	90.77
Dodoma	105	Dodoma Urban	28	28 Kizota	Mixed	7999	8433	16432	3655	4.5	38.4	427.92
Dodoma	104	Dodoma Rural	10	Manchali	Rural	4352	4780	9132	2306	4	91.29	100.03
Dodoma	105	Dodoma Urban	5	5 Makole	Mixed	9198	10219	19417	4554	4.3	19.15	1013.94
Dodoma	102	Mpwapwa	15	Chunyu	Rural	8646	9415	18061	4435	4.1	521.35	34.64
Dodoma	103	Kongwa	11	Sagara	Rural	8567	9630	18197	3387	5.4	234.5	77.6
Dodoma	105	Dodoma Urban	4	4 KiwanjachaNdego	Urban	4949	5663	10612	2360	4.5	3.72	2852.69
Dodoma	105	Dodoma Urban	3	3 Chamwino	Urban	20182	20846	41028	9712	4.2	3.72	11029.03
Dodoma	105	Dodoma Urban	13	13 Dodoma Makulu	Rural	2901	3003	5904	1454	4.1	56.97	103.63
Dodoma	103	Kongwa	1	Kongwa	Mixed	5557	5674	11231	2468	4.6	69.02	162.72
Dodoma	105	Dodoma Urban	25	25 Hazina	Urban	6460	5257	11717	2333	5	12.53	935.12
Dodoma	104	Dodoma Rural	11	Ikowa	Rural	2363	2611	4974	1151	4.3	86.05	57.8
Dodoma	105	Dodoma Urban	22	22 Mkonze	Rural	3683	4144	7827	1733	4.5	85.71	91.32
Dodoma	105	Dodoma Urban	27	27 Majengo	Urban	3308	3593	6901	1763	3.9	0.38	18160.53
Dodoma	105	Dodoma Urban	2	2 Uhuru	Urban	2075	1969	4044	983	4.1	0.73	5539.73
Dodoma	105	Dodoma Urban	18	18 Tambukareli	Mixed	4753	5087	9840	2322	4.2	35.59	276.48
Dodoma	105	Dodoma Urban	1	1 Vivandani	Urban	2768	2938	5706	1396	4.1	0.45	12680
Dodoma	105	Dodoma Urban	15	15 Kikombo	Rural	3821	4084	7905	1928	4.1	93.74	84.33
Dodoma	105	Dodoma Urban	26	26 Madukani	Urban	1362	1450	2812	624	4.5	0.49	5738.78
Dodoma	105	Dodoma Urban	19	19 Kilimani	Urban	2053	2227	4280	957	4.5	9.04	473.45
Dodoma	105	Dodoma Urban	21	21 Kikuyu North	Mixed	3735	2980	6715	1324	5.1	5.96	1126.68
Dodoma	104	Dodoma Rural	12	Msamalo	Rural	4416	5440	9856	2316	4.3	217.07	45.4

Plate_1_2 : Population demographics in the Wami/Ruvu Basin (2002 Census)

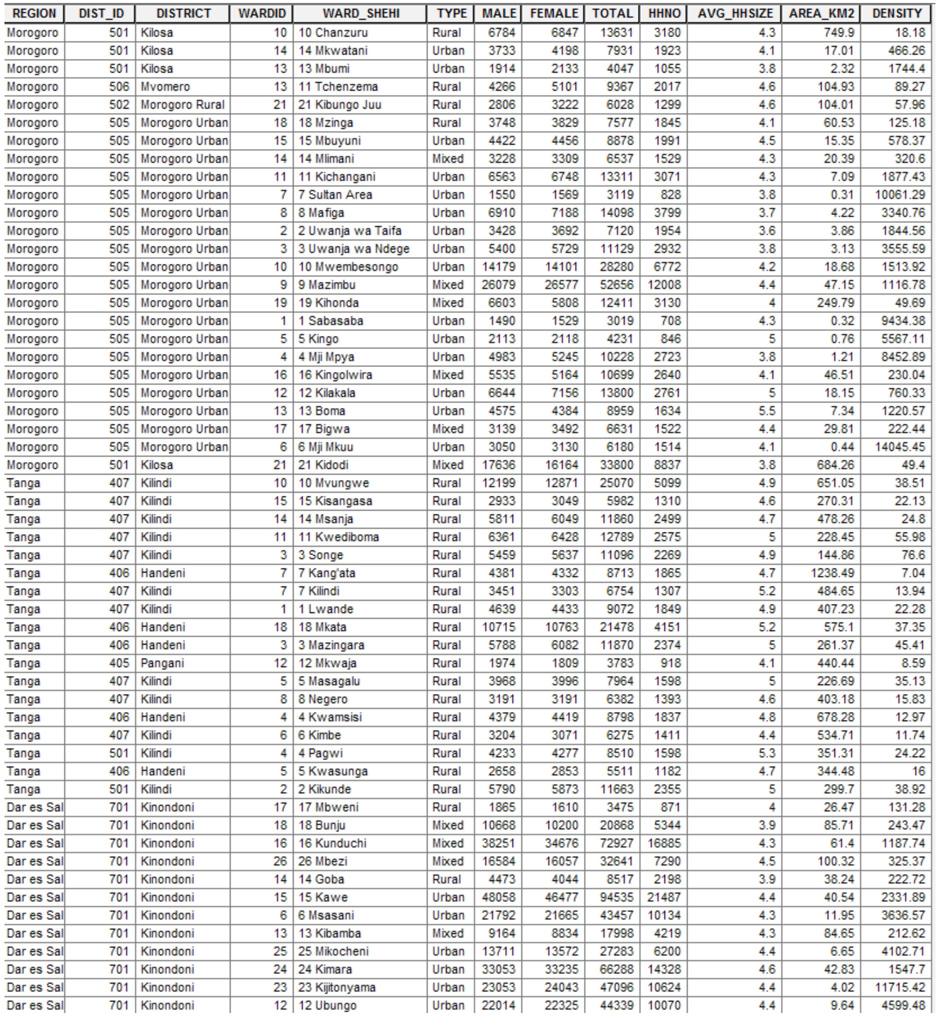


REGION	DIST_ID	DISTRICT	WARDID	WARD_SHEHI	TYPE	MALE	FEMALE	TOTAL	HHNO	AVG_HHSIZE	AREA_KM2	DENSITY
Dodoma	104	Dodoma Rural	12	Msamalo	Rural	4416	5440	9856	2316	4.3	217.07	45.4
Dodoma	105	Dodoma Urban	16	16 Ng'ong'ona	Rural	4113	4472	8585	2024	4.2	127.69	67.23
Dodoma	105	Dodoma Urban	20	20 Kikuyu South	Mixed	1810	2100	3910	930	4.2	2.38	1642.86
Dodoma	103	Kongwa	10	duo	Rural	4223	4665	8888	1787	5	67.73	131.23
Dodoma	103	Kongwa	9	Miali	Rural	12860	14600	27460	4766	5.8	275.73	99.59
Dodoma	102	Mpwapwa	1	Mazae	Rural	6988	7512	14500	3167	4.6	301.85	48.04
Dodoma	102	Mpwapwa	18	MpwapwaMjini	Mixed	9390	9397	18787	3880	4.8	111.77	168.09
Dodoma	104	Dodoma Rural	16	Handali	Mixed	3665	4366	8031	1980	4.1	96.56	83.17
Dodoma	104	Dodoma Rural	14	Muungano	Rural	4100	4781	8881	2199	4	106.36	83.5
Dodoma	103	Kongwa	14	Chamkoroma	Rural	6879	7023	13902	2951	4.7	178.69	77.8
Dodoma	104	Dodoma Rural	17	MvumiMission	Rural	5993	7223	13216	3249	4.1	98.61	134.02
Dodoma	104	Dodoma Rural	13	gandu	Rural	4800	5862	10662	2589	4.1	223.26	47.76
Dodoma	102	Mpwapwa	4	Kimagai	Rural	6593	7072	13665	2928	4.7	215.46	63.42
Dodoma	102	Mpwapwa	2	Ving'hawe	Mixed	5229	5810	11039	2463	4.5	107.04	103.13
Dodoma	104	Dodoma Rural	19	Idifu	Rural	2855	3386	6241	1421	4.4	127.55	48.93
Dodoma	102	Mpwapwa	3	Matomondo	Rural	6719	6941	13660	2975	4.6	340.95	40.06
Dodoma	104	Dodoma Rural	20	IringaMvumi	Rural	4413	5101	9514	2116	4.5	105.23	90.41
Dodoma	102	Mpwapwa	14	Berege	Rural	7576	8194	15770	3406	4.6	492.35	32.03
Dodoma	102	Mpwapwa	13	Mima	Rural	8229	9112	17341	4088	4.2	465.45	37.26
Dodoma	102	Mpwapwa	17	GodeGode	Rural	3631	3754	7385	1786	4.1	231.74	31.87
Dodoma	102	Mpwapwa	5	Kibakwe	Mixed	8850	9671	18521	4264	4.3	370.76	49.95
Dodoma	102	Mpwapwa	12	Wotta	Rural	4986	5552	10538	2215	4.8	288.41	36.54
Dodoma	102	Mpwapwa	6	Lumuma	Rural	6340	6634	12974	2952	4.4	401.05	32.35
Dodoma	102	Mpwapwa	7	Luhundwa	Rural	6774	7754	14528	3201	4.5	391.47	37.11
Dodoma	102	Mpwapwa	16	Mbuga	Rural	3980	4273	8253	1570	5.3	306.29	26.95
Iringa	1107	Kilolo	6	6 Mahenge	Rural	10075	9349	19424	4347	4.5	1314.3	14.78
Manyara	2105	Kiteto	4	4 Olboloti	Mixed	7575	7321	14896	3324	4.5	518.15	28.75
Manyara	2105	Kiteto	3	3 Njoro	Rural	4739	4462	9201	2098	4.4	516.07	17.83
Manyara	2105	Kiteto	2	2 Partimbo	Rural	9982	9671	19653	4173	4.7	1845.2	10.65
Manyara	2105	Kiteto	14	14 Matui	Mixed	9153	9191	18344	3879	4.7	169.37	108.31
Manyara	2105	Kiteto	8	8 Lengatei	Rural	3627	3849	7476	1500	5	879.26	8.5
Manyara	2105	Kiteto	13	13 Engusero	Rural	6161	6157	12318	2613	4.7	363	33.93
Manyara	2105	Kiteto	9	9 Sunya	Rural	7237	6625	13862	2741	5.1	1296.22	10.69
Manyara	2105	Kiteto	12	12 Dosidosi	Rural	2634	2823	5457	1098	5	18.59	293.54
Manyara	2105	Kiteto	12	12 Dosidosi	Rural	2634	2823	5457	1098	5	61.32	88.99
Manyara	2105	Kiteto	11	11 Songambele	Rural	5595	5397	10992	2219	5	310.33	35.42
Manyara	2105	Kiteto	10	10 Dongo	Rural	7025	7071	14096	2706	5.2	827.89	17.03
Morogoro	506	Mvomero	4	4 Kibati	Rural	8788	8954	17742	3627	4.9	520.56	34.08
Morogoro	501	Kilosa	1	1 Chakwale	Rural	14233	14920	29153	5628	5.2	325.84	89.47
Morogoro	506	Mvomero	9	9 Kanga	Rural	7847	6852	14699	3377	4.4	705.52	20.83
Morogoro	501	Kilosa	2	2 Iyogwe	Rural	8489	8898	17387	3408	5.1	320.8	54.2
Morogoro	501	Kilosa	37	37 Kibedya	Rural	7576	8125	15701	2984	5.3	142.46	110.21
Morogoro	506	Mvomero	7	7 Diongoya	Rural	8799	8603	17402	3814	4.6	164.81	105.59
Morogoro	506	Mvomero	3	3 Maskati	Rural	5242	5386	10628	2073	5.1	287.15	37.01
Morogoro	501	Kilosa	36	36 Gairo	Mixed	17126	18512	35638	6580	5.4	161.61	220.52
Morogoro	506	Mvomero	6	6 Mhonda	Mixed	8296	8463	16759	3627	4.6	51.9	322.91
Morogoro	501	Kilosa	3	3 Berega	Rural	7310	7742	15052	2751	5.5	223.04	67.49
Morogoro	501	Kilosa	5	5 Mamboya	Rural	10255	10442	20697	3644	5.7	493.05	41.98
Morogoro	506	Mvomero	5	5 Sungaji	Rural	7024	7030	14054	3258	4.3	148.14	94.87
Morogoro	501	Kilosa	4	4 Magubike	Mixed	7181	7083	14264	2935	4.9	326.6	43.67
Morogoro	506	Mvomero	8	8 Mtibwa	Mixed	14736	12479	27215	6127	4.4	320.84	84.82
Morogoro	506	Mvomero	2	2 Hembeti	Rural	9076	9209	18285	3990	4.6	337.71	54.14
Morogoro	506	Mvomero	1	1 Mvomero	Mixed	15227	14221	29448	6367	4.6	1260.64	23.36
Morogoro	502	Morogoro Rural	10	10 Mkambalani	Rural	5382	4894	10276	2183	4.7	1761.42	5.83
Morogoro	501	Kilosa	35	35 Rubeho	Rural	8115	8905	17020	2888	5.9	120.62	141.1

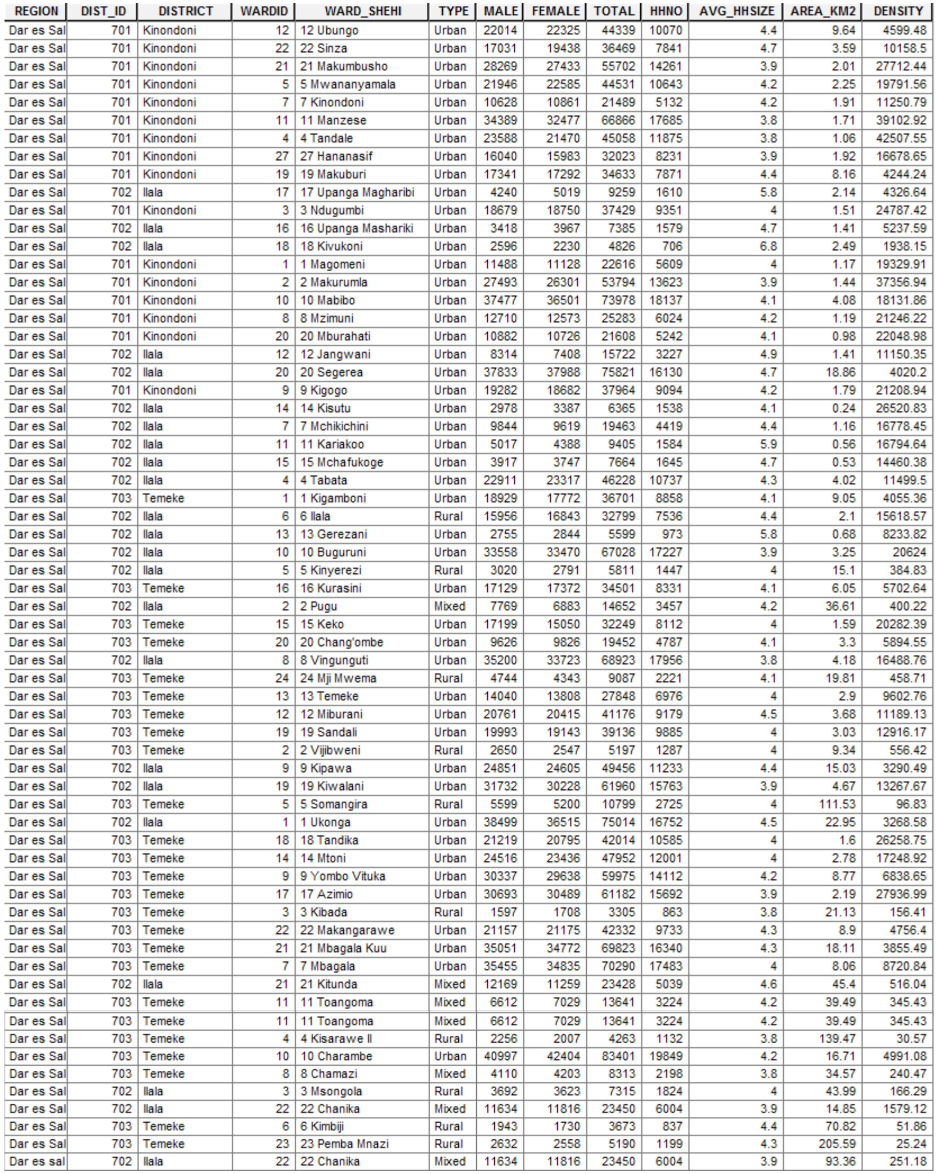


REGION	DIST_ID	DISTRICT	WARDID	WARD_SHEHI	TYPE	MALE	FEMALE	TOTAL	HHNO	AVG_HHSIZE	AREA_KM2	DENSITY
Morogoro	501	Kilosa	35	35 Rubeho	Rural	8115	8905	17020	2888	5.9	120.62	141.1
Morogoro	501	Kilosa	34	34 Mandege	Rural	3756	3491	7247	1110	6.5	202.26	35.83
Morogoro	501	Kilosa	33	33 Chagongwe	Rural	3494	3843	7337	1324	5.5	140.38	52.27
Morogoro	501	Kilosa	8	8 Msowero	Mixed	8550	8241	16791	4050	4.1	535.54	31.35
Morogoro	501	Kilosa	32	32 Chanjale	Rural	6284	6551	12835	2166	5.9	388.04	33.08
Morogoro	501	Kilosa	31	31 Lubuji	Rural	2888	2855	5743	980	5.9	317.74	18.07
Morogoro	501	Kilosa	30	30 Kidete	Rural	4933	4747	9680	2266	4.3	368.97	26.24
Morogoro	502	Morogoro Rural	11	11 Mikese	Rural	9459	8711	18170	4014	4.5	418.43	43.42
Morogoro	506	Mvomero	14	14 Mzumbe	Rural	8489	7955	16444	3932	4.2	493.81	33.3
Morogoro	502	Morogoro Rural	14	14 Ngerengere	Mixed	8028	8124	16152	3382	4.8	610.53	26.46
Morogoro	501	Kilosa	29	29 Masanze	Rural	3403	2988	6391	1587	4	470.67	13.58
Morogoro	502	Morogoro Rural	12	12 Kidugalo	Rural	5371	5335	10706	2211	4.8	494.58	21.65
Morogoro	501	Kilosa	15	15 Magomeni	Urban	4138	4270	8408	2115	4	137.66	61.08
Morogoro	501	Kilosa	28	28 Lumuma	Rural	5159	5160	10319	2297	4.5	308.26	33.47
Morogoro	506	Mvomero	17	17 Melela	Rural	4957	5249	10206	2548	4	609.27	16.75
Morogoro	501	Kilosa	12	12 Kimamba 'B'	Urban	2404	2495	4899	1288	3.8	8.95	547.37
Morogoro	501	Kilosa	16	16 Kasiki	Urban	2867	2878	5745	1332	4.3	14.22	404.01
Morogoro	501	Kilosa	11	11 Kimamba 'A'	Urban	2762	2901	5663	1496	3.8	11.32	500.27
Morogoro	502	Morogoro Rural	17	17 Kiroka	Rural	10528	10919	21447	4937	4.3	197.29	108.71
Morogoro	502	Morogoro Rural	15	15 Tununguo	Rural	2968	2325	5293	1099	4.8	656.89	8.06
Morogoro	502	Morogoro Rural	19	19 Tegetero	Rural	3046	3242	6288	1253	5	82.11	76.58
Morogoro	502	Morogoro Rural	16	16 Kinole	Rural	5975	6056	12031	2363	5.1	60.15	200.02
Morogoro	502	Morogoro Rural	18	18 Mkuyuni	Rural	9059	9862	18921	3930	4.8	132.44	142.86
Morogoro	506	Mvomero	15	15 Mlali	Rural	9694	9672	19366	4597	4.2	287.97	67.25
Morogoro	501	Kilosa	18	18 Kilangali	Rural	3579	3564	7143	1676	4.3	504.16	14.17
Morogoro	501	Kilosa	27	27 Zombo	Rural	4402	4378	8780	2135	4.1	294.57	29.81
Morogoro	502	Morogoro Rural	13	13 Mkulazi	Rural	2575	2591	5166	1074	4.8	849.21	6.08
Morogoro	502	Morogoro Rural	20	20 Kibogwa	Rural	3676	4309	7985	1704	4.7	72.59	110
Morogoro	501	Kilosa	26	26 Ulaya	Rural	6628	6495	13123	3126	4.2	1178.27	11.14
Morogoro	502	Morogoro Rural	25	25 Tawa	Rural	5205	5522	10727	2150	5	58.42	183.62
Morogoro	502	Morogoro Rural	23	23 Lundi	Rural	4772	5059	9831	2084	4.7	116.71	84.23
Morogoro	506	Mvomero	10	10 Bunduki	Rural	3329	3712	7041	1510	4.7	66.99	105.11
Morogoro	502	Morogoro Rural	22	22 Kisemu	Mixed	6510	7079	13589	3036	4.5	68.13	199.46
Morogoro	506	Mvomero	12	12 Langali	Mixed	4117	4403	8520	2013	4.2	43.06	197.86
Morogoro	501	Kilosa	25	25 Uleling'ombe	Rural	1628	1683	3311	646	5.1	247.4	13.38
Morogoro	502	Morogoro Rural	4	4 Selembala	Rural	2358	2330	4688	998	4.7	622.63	7.53
Morogoro	506	Mvomero	11	11 Kikeo	Rural	6398	7173	13571	2979	4.6	326.53	41.56
Morogoro	502	Morogoro Rural	24	24 Mtombozi	Rural	4174	4686	8860	1723	5.1	78.11	113.43
Morogoro	502	Morogoro Rural	3	3 Mvuha	Rural	4692	4786	9478	2089	4.5	428.92	22.1
Morogoro	501	Kilosa	24	24 Kisanga	Mixed	5448	4872	10320	2476	4.2	450.84	22.89
Morogoro	502	Morogoro Rural	9	9 Singisa	Rural	5322	5961	11283	2363	4.8	281.67	40.06
Morogoro	502	Morogoro Rural	1	1 Kasanga	Rural	4629	5377	10006	2117	4.7	94	106.45
Morogoro	502	Morogoro Rural	6	6 Bwakila Juu	Rural	2623	3036	5659	1199	4.7	108.81	52.01
Morogoro	502	Morogoro Rural	2	2 Kolero	Rural	3951	4410	8361	2025	4.1	121.24	68.96
Morogoro	502	Morogoro Rural	8	8 Mngazi	Rural	4142	4344	8486	1914	4.4	143.06	59.32
Morogoro	502	Morogoro Rural	5	5 Bwakila Chini	Rural	5647	5954	11601	2568	4.5	448.58	25.86
Morogoro	501	Kilosa	6	6 Dumila	Mixed	10271	10066	20337	4110	4.9	537.19	37.86
Morogoro	501	Kilosa	7	7 Magole	Mixed	8913	8717	17630	3891	4.5	218.13	80.82
Morogoro	501	Kilosa	9	9 Rudewa	Rural	6814	7082	13896	3133	4.4	143.59	96.78
Morogoro	501	Kilosa	17	17 Mabwerebwere	Rural	9932	10004	19936	4895	4.1	440.98	45.21
Morogoro	502	Morogoro Rural	7	7 Kisaki	Rural	6387	6501	12888	3008	4.3	4962.43	2.6
Morogoro	506	Mvomero	16	16 Doma	Rural	4971	4807	9778	2458	4	509.82	19.18
Morogoro	501	Kilosa	23	23 Malolo	Rural	4787	4164	8951	2224	4	883.35	10.13
Morogoro	501	Kilosa	19	19 Mikumi	Mixed	8067	7708	15775	3678	4.3	1314.3	12
Morogoro	501	Kilosa	10	10 Chanzuru	Rural	6784	6847	13631	3180	4.3	749.9	18.18

Plate_1_3 : Population demographics in the Wami/Ruvu Basin (2002 Census)

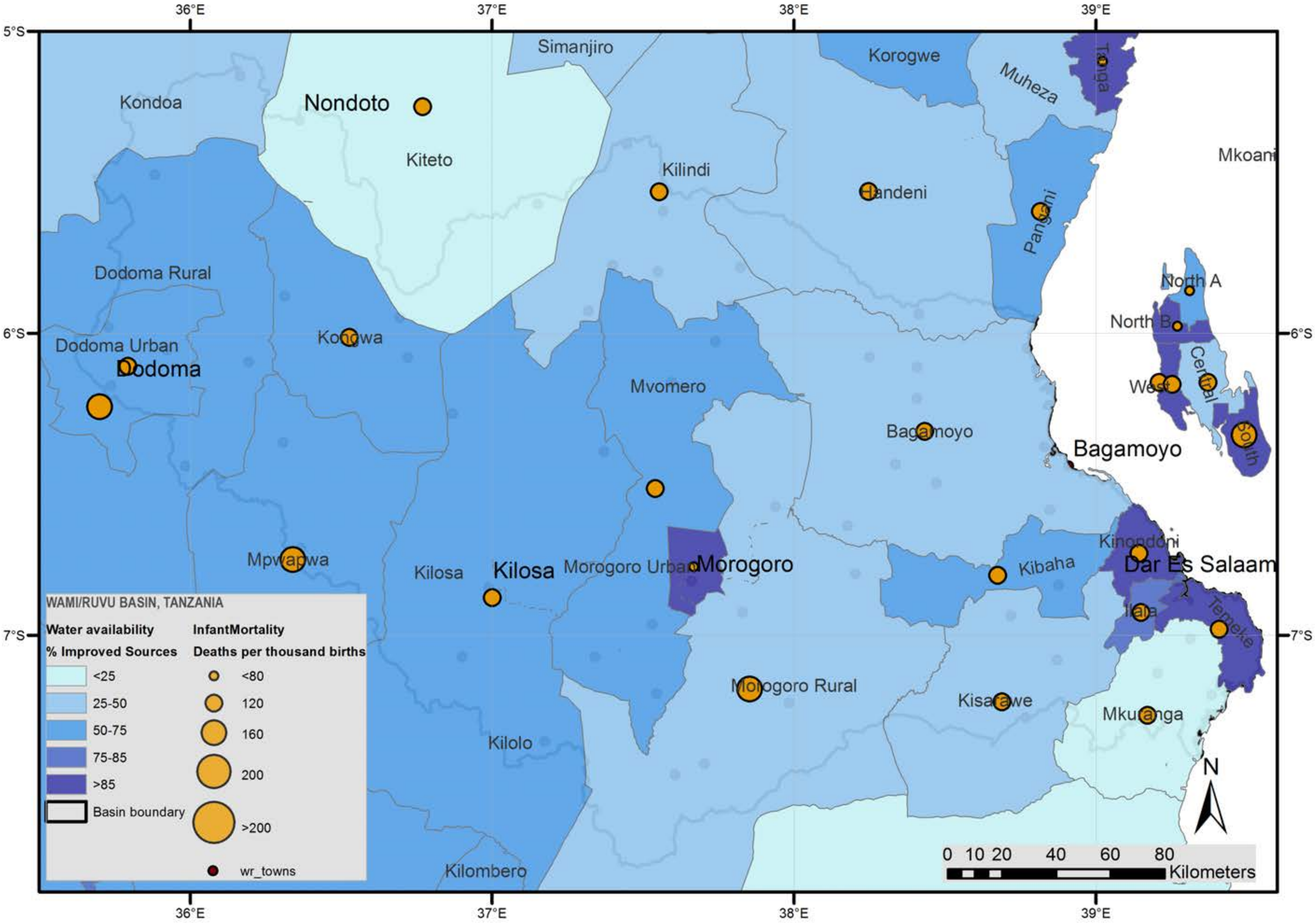


REGION	DIST_ID	DISTRICT	WARDID	WARD_SHEHI	TYPE	MALE	FEMALE	TOTAL	HHNO	AVG_HHSIZE	AREA_KM2	DENSITY
Morogoro	501	Kilosa	10	10 Chanzuru	Rural	6784	6847	13631	3180	4.3	749.9	18.18
Morogoro	501	Kilosa	14	14 Mkwatani	Urban	3733	4198	7931	1923	4.1	17.01	466.26
Morogoro	501	Kilosa	13	13 Mbumi	Urban	1914	2133	4047	1055	3.8	2.32	1744.4
Morogoro	506	Mvomero	13	11 Tchenzema	Rural	4266	5101	9367	2017	4.6	104.93	89.27
Morogoro	502	Morogoro Rural	21	21 Kibungo Juu	Rural	2806	3222	6028	1299	4.6	104.01	57.96
Morogoro	505	Morogoro Urban	18	18 Mzinga	Rural	3748	3829	7577	1845	4.1	60.53	125.18
Morogoro	505	Morogoro Urban	15	15 Mbuyuni	Urban	4422	4456	8878	1991	4.5	15.35	578.37
Morogoro	505	Morogoro Urban	14	14 Mlimani	Mixed	3228	3309	6537	1529	4.3	20.39	320.6
Morogoro	505	Morogoro Urban	11	11 Kichangani	Urban	6563	6748	13311	3071	4.3	7.09	1877.43
Morogoro	505	Morogoro Urban	7	7 Sultan Area	Urban	1550	1569	3119	828	3.8	0.31	10061.29
Morogoro	505	Morogoro Urban	8	8 Mafiga	Urban	6910	7188	14098	3799	3.7	4.22	3340.76
Morogoro	505	Morogoro Urban	2	2 Uwanja wa Taifa	Urban	3428	3692	7120	1954	3.6	3.86	1844.56
Morogoro	505	Morogoro Urban	3	3 Uwanja wa Ndege	Urban	5400	5729	11129	2932	3.8	3.13	3555.59
Morogoro	505	Morogoro Urban	10	10 Mwembesongo	Urban	14179	14101	28280	6772	4.2	18.68	1513.92
Morogoro	505	Morogoro Urban	9	9 Mazimbu	Mixed	26079	26577	52656	12008	4.4	47.15	1116.78
Morogoro	505	Morogoro Urban	19	19 Kihonda	Mixed	6603	5808	12411	3130	4	249.79	49.69
Morogoro	505	Morogoro Urban	1	1 Sabasaba	Urban	1490	1529	3019	708	4.3	0.32	9434.38
Morogoro	505	Morogoro Urban	5	5 Kingo	Urban	2113	2118	4231	846	5	0.76	5567.11
Morogoro	505	Morogoro Urban	4	4 Mji Mpya	Urban	4983	5245	10228	2723	3.8	1.21	8452.89
Morogoro	505	Morogoro Urban	16	16 Kingolwira	Mixed	5535	5164	10699	2640	4.1	46.51	230.04
Morogoro	505	Morogoro Urban	12	12 Kilakala	Urban	6644	7156	13800	2761	5	18.15	760.33
Morogoro	505	Morogoro Urban	13	13 Boma	Urban	4575	4384	8959	1634	5.5	7.34	1220.57
Morogoro	505	Morogoro Urban	17	17 Bigwa	Mixed	3139	3492	6631	1522	4.4	29.81	222.44
Morogoro	505	Morogoro Urban	6	6 Mji Mkuu	Urban	3050	3130	6180	1514	4.1	0.44	14045.45
Morogoro	501	Kilosa	21	21 Kidodi	Mixed	17636	16164	33800	8837	3.8	684.26	49.4
Tanga	407	Kilindi	10	10 Mvungwe	Rural	12199	12871	25070	5099	4.9	651.05	38.51
Tanga	407	Kilindi	15	15 Kisangasa	Rural	2933	3049	5982	1310	4.6	270.31	22.13
Tanga	407	Kilindi	14	14 Msanja	Rural	5811	6049	11860	2499	4.7	478.26	24.8
Tanga	407	Kilindi	11	11 Kwediboma	Rural	6361	6428	12789	2575	5	228.45	55.98
Tanga	407	Kilindi	3	3 Songe	Rural	5459	5637	11096	2269	4.9	144.86	76.6
Tanga	406	Handeni	7	7 Kang'ata	Rural	4381	4332	8713	1865	4.7	1238.49	7.04
Tanga	407	Kilindi	7	7 Kilindi	Rural	3451	3303	6754	1307	5.2	484.65	13.94
Tanga	407	Kilindi	1	1 Lwande	Rural	4639	4433	9072	1849	4.9	407.23	22.28
Tanga	406	Handeni	18	18 Mkata	Rural	10715	10763	21478	4151	5.2	575.1	37.35
Tanga	406	Handeni	3	3 Mazingara	Rural	5788	6082	11870	2374	5	261.37	45.41
Tanga	405	Pangani	12	12 Mkwaja	Rural	1974	1809	3783	918	4.1	440.44	8.59
Tanga	407	Kilindi	5	5 Masagalu	Rural	3968	3996	7964	1598	5	226.69	35.13
Tanga	407	Kilindi	8	8 Negero	Rural	3191	3191	6382	1393	4.6	403.18	15.83
Tanga	406	Handeni	4	4 Kwamsisi	Rural	4379	4419	8798	1837	4.8	678.28	12.97
Tanga	407	Kilindi	6	6 Kimbe	Rural	3204	3071	6275	1411	4.4	534.71	11.74
Tanga	501	Kilindi	4	4 Pagwi	Rural	4233	4277	8510	1598	5.3	351.31	24.22
Tanga	406	Handeni	5	5 Kwasunga	Rural	2658	2853	5511	1182	4.7	344.48	16
Tanga	501	Kilindi	2	2 Kikunde	Rural	5790	5873	11663	2355	5	299.7	38.92
Dar es Sal	701	Kinondoni	17	17 Mbweni	Rural	1865	1610	3475	871	4	26.47	131.28
Dar es Sal	701	Kinondoni	18	18 Bunju	Mixed	10668	10200	20868	5344	3.9	85.71	243.47
Dar es Sal	701	Kinondoni	16	16 Kunduchi	Mixed	38251	34676	72927	16885	4.3	61.4	1187.74
Dar es Sal	701	Kinondoni	26	26 Mbezi	Mixed	16584	16057	32641	7290	4.5	100.32	325.37
Dar es Sal	701	Kinondoni	14	14 Goba	Rural	4473	4044	8517	2198	3.9	38.24	222.72
Dar es Sal	701	Kinondoni	15	15 Kawe	Urban	48058	46477	94535	21487	4.4	40.54	2331.89
Dar es Sal	701	Kinondoni	6	6 Msasani	Urban	21792	21665	43457	10134	4.3	11.95	3636.57
Dar es Sal	701	Kinondoni	13	13 Kibamba	Mixed	9164	8834	17998	4219	4.3	84.65	212.62
Dar es Sal	701	Kinondoni	25	25 Mikocheni	Urban	13711	13572	27283	6200	4.4	6.65	4102.71
Dar es Sal	701	Kinondoni	24	24 Kimara	Urban	33053	33235	66288	14328	4.6	42.83	1547.7
Dar es Sal	701	Kinondoni	23	23 Kijitonyama	Urban	23053	24043	47096	10624	4.4	4.02	11715.42
Dar es Sal	701	Kinondoni	12	12 Ubungo	Urban	22014	22325	44339	10070	4.4	9.64	4599.48



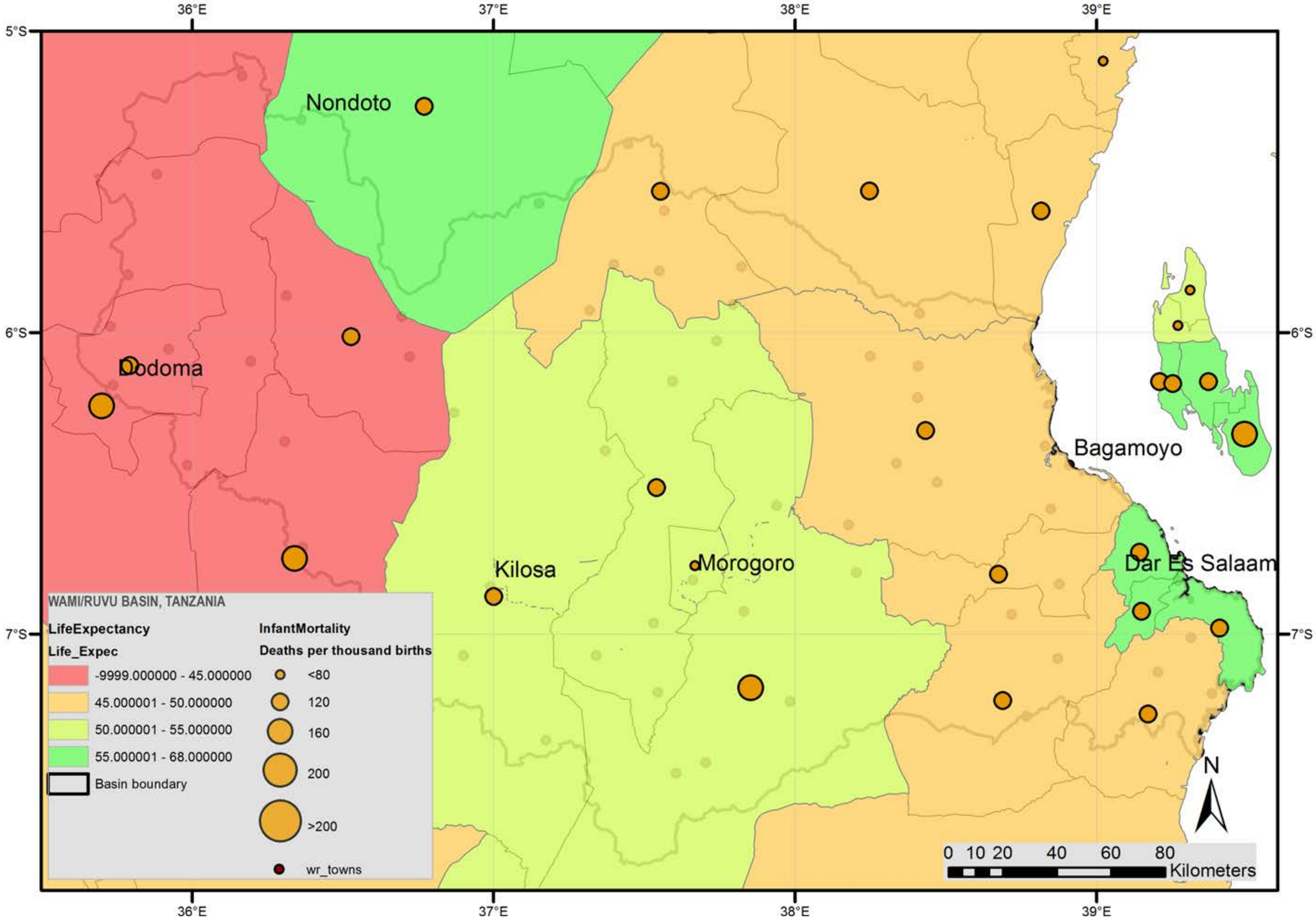
REGION	DIST_ID	DISTRICT	WARDID	WARD_SHEHI	TYPE	MALE	FEMALE	TOTAL	HHNO	AVG_HHSIZE	AREA_KM2	DENSITY
Dar es Sal	701	Kinondoni	12	12 Ubungo	Urban	22014	22325	44339	10070	4.4	9.64	4599.48
Dar es Sal	701	Kinondoni	22	22 Sinza	Urban	17031	19438	36469	7841	4.7	3.59	10158.5
Dar es Sal	701	Kinondoni	21	21 Makumbusho	Urban	28269	27433	55702	14261	3.9	2.01	27712.44
Dar es Sal	701	Kinondoni	5	5 Mwananyamala	Urban	21946	22585	44531	10643	4.2	2.25	19791.56
Dar es Sal	701	Kinondoni	7	7 Kinondoni	Urban	10628	10861	21489	5132	4.2	1.91	11250.79
Dar es Sal	701	Kinondoni	11	11 Manzese	Urban	34389	32477	66866	17685	3.8	1.71	39102.92
Dar es Sal	701	Kinondoni	4	4 Tandale	Urban	23588	21470	45058	11875	3.8	1.06	42507.55
Dar es Sal	701	Kinondoni	27	27 Hananasif	Urban	16040	15983	32023	8231	3.9	1.92	16678.65
Dar es Sal	701	Kinondoni	19	19 Makuburi	Urban	17341	17292	34633	7871	4.4	8.16	4244.24
Dar es Sal	702	Ilala	17	17 Upanga Magharibi	Urban	4240	5019	9259	1610	5.8	2.14	4326.64
Dar es Sal	701	Kinondoni	3	3 Ndugumbi	Urban	18679	18750	37429	9351	4	1.51	24787.42
Dar es Sal	702	Ilala	16	16 Upanga Mashariki	Urban	3418	3967	7385	1579	4.7	1.41	5237.59
Dar es Sal	702	Ilala	18	18 Kivukoni	Urban	2596	2230	4826	706	6.8	2.49	1938.15
Dar es Sal	701	Kinondoni	1	1 Magomeni	Urban	11488	11128	22616	5609	4	1.17	19329.91
Dar es Sal	701	Kinondoni	2	2 Makurumla	Urban	27493	26301	53794	13623	3.9	1.44	37356.94
Dar es Sal	701	Kinondoni	10	10 Mabibo	Urban	37477	36501	73978	18137	4.1	4.08	18131.86
Dar es Sal	701	Kinondoni	8	8 Mzimuni	Urban	12710	12573	25283	6024	4.2	1.19	21246.22
Dar es Sal	701	Kinondoni	20	20 Mburahati	Urban	10882	10726	21608	5242	4.1	0.98	22048.98
Dar es Sal	702	Ilala	12	12 Jangwani	Urban	8314	7408	15722	3227	4.9	1.41	11150.35
Dar es Sal	702	Ilala	20	20 Segerea	Urban	37833	37988	75821	16130	4.7	18.86	4020.2
Dar es Sal	701	Kinondoni	9	9 Kigogo	Urban	19282	18682	37964	9094	4.2	1.79	21208.94
Dar es Sal	702	Ilala	14	14 Kisutu	Urban	2978	3387	6365	1538	4.1	0.24	26520.83
Dar es Sal	702	Ilala	7	7 Mchikichini	Urban	9844	9619	19463	4419	4.4	1.16	16778.45
Dar es Sal	702	Ilala	11	11 Kariakoo	Urban	5017	4388	9405	1584	5.9	0.56	16794.64
Dar es Sal	702	Ilala	15	15 Mchafukoge	Urban	3917	3747	7664	1645	4.7	0.53	14460.38
Dar es Sal	702	Ilala	4	4 Tabata	Urban	22911	23317	46228	10737	4.3	4.02	11499.5
Dar es Sal	703	Temeke	1	1 Kigamboni	Urban	18929	17772	36701	8858	4.1	9.05	4055.36
Dar es Sal	702	Ilala	6	6 Ilala	Rural	15956	16843	32799	7536	4.4	2.1	15618.57
Dar es Sal	702	Ilala	13	13 Gerezani	Urban	2755	2844	5599	973	5.8	0.68	8233.82
Dar es Sal	702	Ilala	10	10 Buguruni	Urban	33558	33470	67028	17227	3.9	3.25	20624
Dar es Sal	702	Ilala	5	5 Kinyerezi	Rural	3020	2791	5811	1447	4	15.1	384.83
Dar es Sal	703	Temeke	16	16 Kurasini	Urban	17129	17372	34501	8331	4.1	6.05	5702.64
Dar es Sal	702	Ilala	2	2 Pugu	Mixed	7769	6883	14652	3457	4.2	36.61	400.22
Dar es Sal	703	Temeke	15	15 Keko	Urban	17199	15050	32249	8112	4	1.59	20282.39
Dar es Sal	703	Temeke	20	20 Chang'ombe	Urban	9626	9826	19452	4787	4.1	3.3	5894.55
Dar es Sal	702	Ilala	8	8 Vingunguti	Urban	35200	33723	68923	17956	3.8	4.18	16488.76
Dar es Sal	703	Temeke	24	24 Mji Mwema	Rural	4744	4343	9087	2221	4.1	19.81	458.71
Dar es Sal	703	Temeke	13	13 Temeke	Urban	14040	13808	27848	6976	4	2.9	9602.76
Dar es Sal	703	Temeke	12	12 Miburani	Urban	20761	20415	41176	9179	4.5	3.68	11189.13
Dar es Sal	703	Temeke	19	19 Sandali	Urban	19993	19143	39136	9885	4	3.03	12916.17
Dar es Sal	703	Temeke	2	2 Vijibweni	Rural	2650	2547	5197	1287	4	9.34	556.42
Dar es Sal	702	Ilala	9	9 Kipawa	Urban	24851	24605	49456	11233	4.4	15.03	3290.49
Dar es Sal	702	Ilala	19	19 Kiwalani	Urban	31732	30228	61960	15763	3.9	4.67	13267.67
Dar es Sal	703	Temeke	5	5 Somangira	Rural	5599	5200	10799	2725	4	111.53	96.83
Dar es Sal	702	Ilala	1	1 Ukonga	Urban	38499	36515	75014	16752	4.5	22.95	3268.58
Dar es Sal	703	Temeke	18	18 Tandika	Urban	21219	20795	42014	10585	4	1.6	26258.75
Dar es Sal	703	Temeke	14	14 Mtoni	Urban	24516	23436	47952	12001	4	2.78	17248.92
Dar es Sal	703	Temeke	9	9 Yombo Vituka	Urban	30337	29638	59975	14112	4.2	8.77	6838.65
Dar es Sal	703	Temeke	17	17 Azimio	Urban	30693	30489	61182	15692	3.9	2.19	27936.99
Dar es Sal	703	Temeke	3	3 Kibada	Rural	1597	1708	3305	863	3.8	21.13	156.41
Dar es Sal	703	Temeke	22	22 Makangarawe	Urban	21157	21175	42332	9733	4.3	8.9	4756.4
Dar es Sal	703	Temeke	21	21 Mbagala Kuu	Urban	35051	34772	69823	16340	4.3	18.11	3855.49
Dar es Sal	703	Temeke	7	7 Mbagala	Urban	35455	34835	70290	17483	4	8.06	8720.84
Dar es Sal	702	Ilala	21	21 Kitunda	Mixed	12169	11259	23428	5039	4.6	45.4	516.04
Dar es Sal	703	Temeke	11	11 Toangoma	Mixed	6612	7029	13641	3224	4.2	39.49	345.43
Dar es Sal	703	Temeke	11	11 Toangoma	Mixed	6612	7029	13641	3224	4.2	39.49	345.43
Dar es Sal	703	Temeke	4	4 Kisarawe II	Rural	2256	2007	4263	1132	3.8	139.47	30.57
Dar es Sal	703	Temeke	10	10 Charambe	Urban	40997	42404	83401	19849	4.2	16.71	4991.08
Dar es Sal	703	Temeke	8	8 Chamazi	Mixed	4110	4203	8313	2198	3.8	34.57	240.47
Dar es Sal	702	Ilala	3	3 Msongola	Rural	3692	3623	7315	1824	4	43.99	166.29
Dar es Sal	702	Ilala	22	22 Chanika	Mixed	11634	11816	23450	6004	3.9	14.85	1579.12
Dar es Sal	703	Temeke	6	6 Kimbiji	Rural	1943	1730	3673	837	4.4	70.82	51.86
Dar es Sal	703	Temeke	23	23 Pemba Mnazi	Rural	2632	2558	5190	1199	4.3	205.59	25.24
Dar es sal	702	Ilala	22	22 Chanika	Mixed	11634	11816	23450	6004	3.9	93.36	251.18

Map_1_8_A: Water availability (%households with access to improved water source) and infant mortality



Data source: WWF Social measures report 2009, WWF Coastal East Africa Initiative.

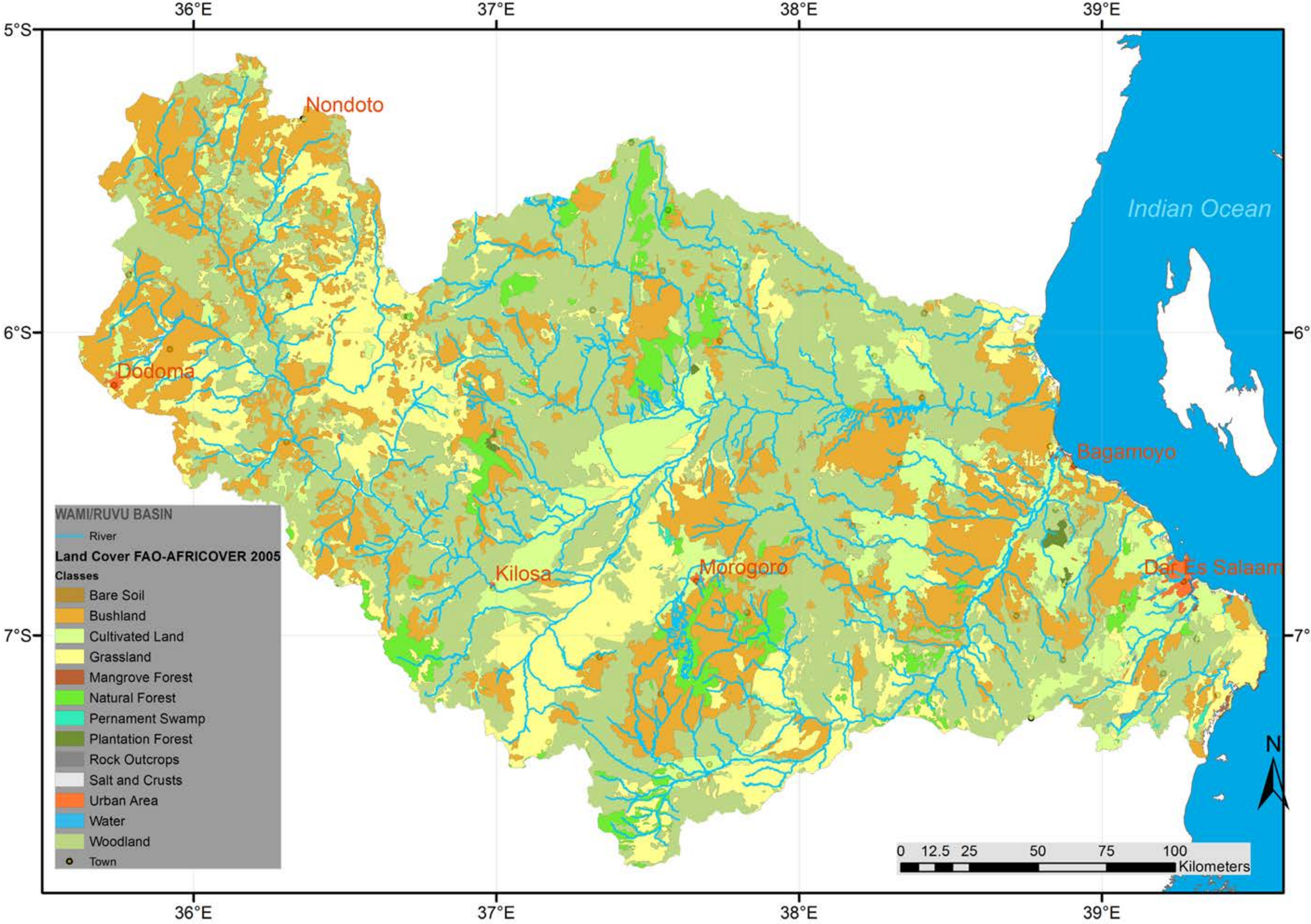
Map_1_8_B: Life expectancy and infant mortality



Data source: WWF Social measures report 2009, WWF Coastal East Africa Initiative.

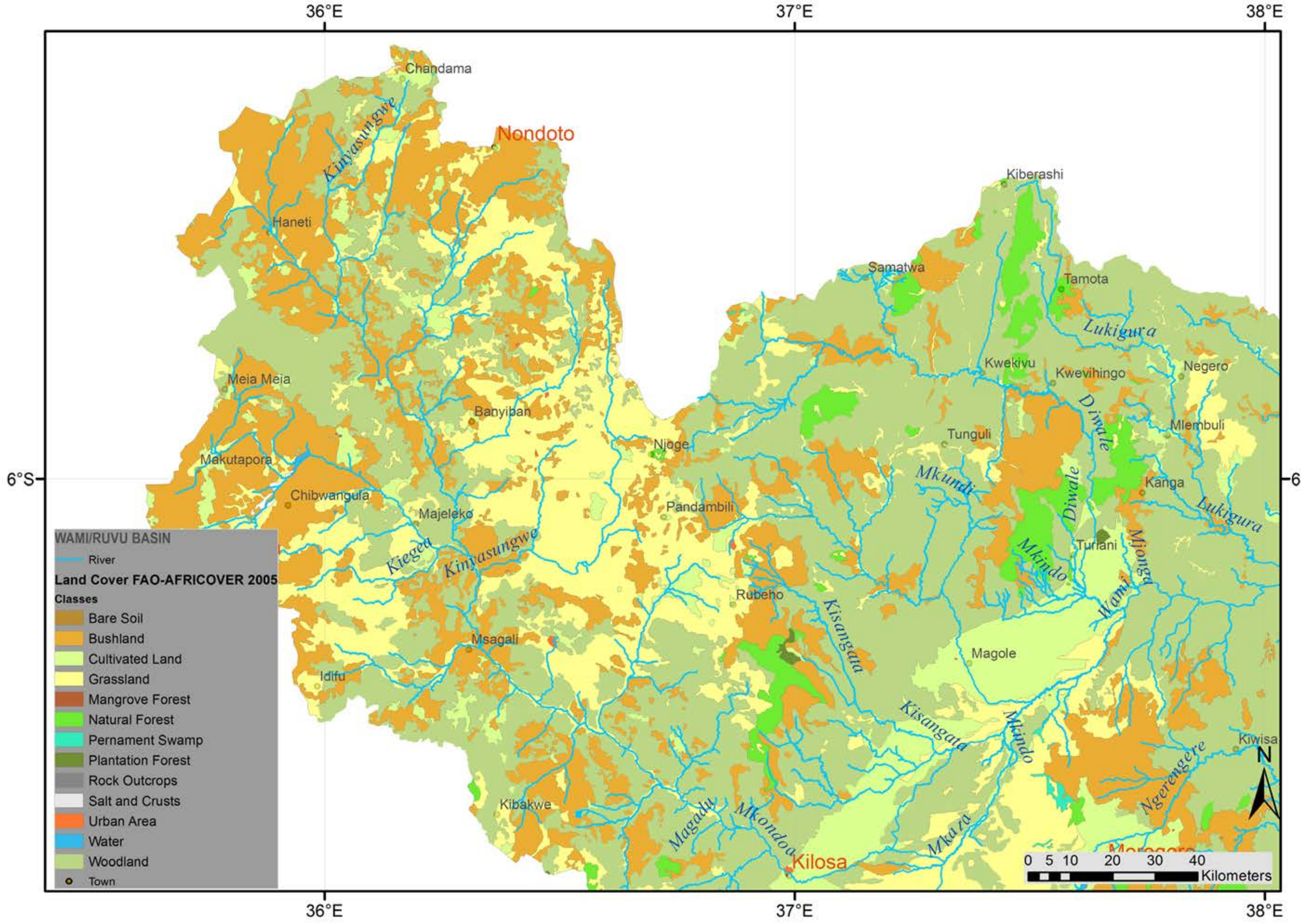
Map_1_9: Transportation - roads, rail and bridges

Map_1_10: Land cover in the Wami/Ruvu Basin



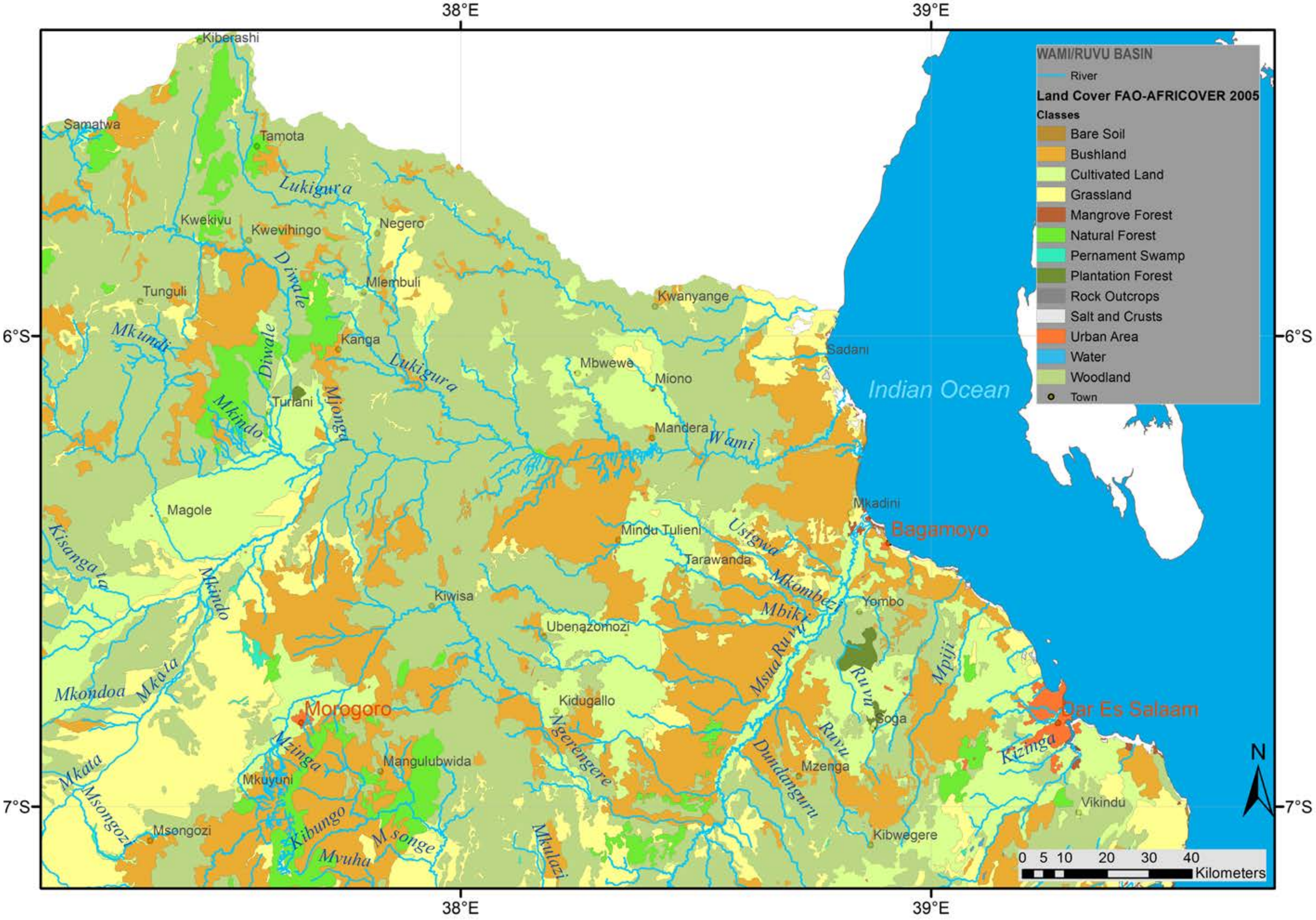
Data Source: AFRICOVER 2005

Map_1_10_A: Land cover in western Wami/Ruvu Basin



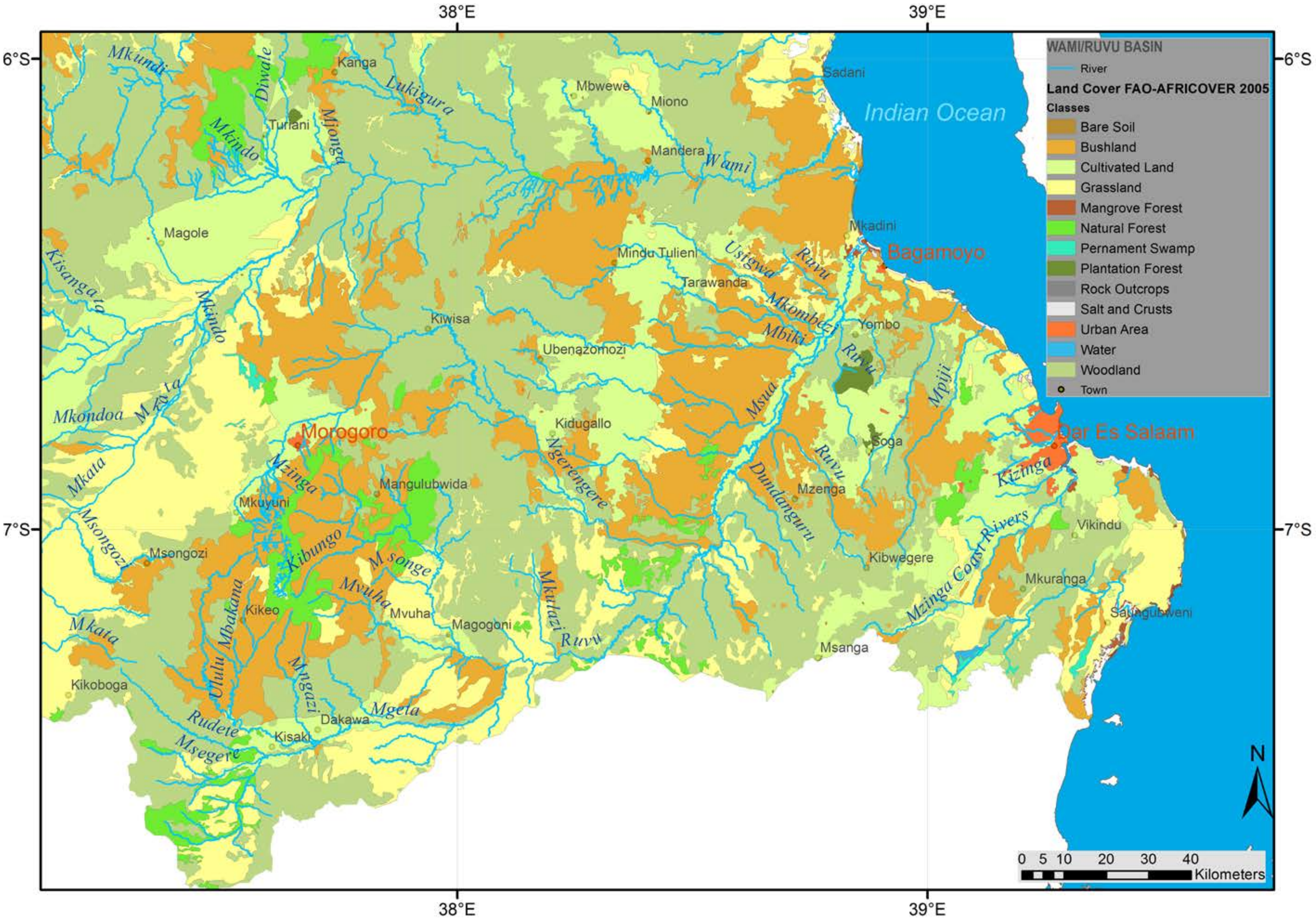
Data Source: AFRICOVER 2005

Map_1_10_B: Land cover in northern Wami/Ruvu Basin



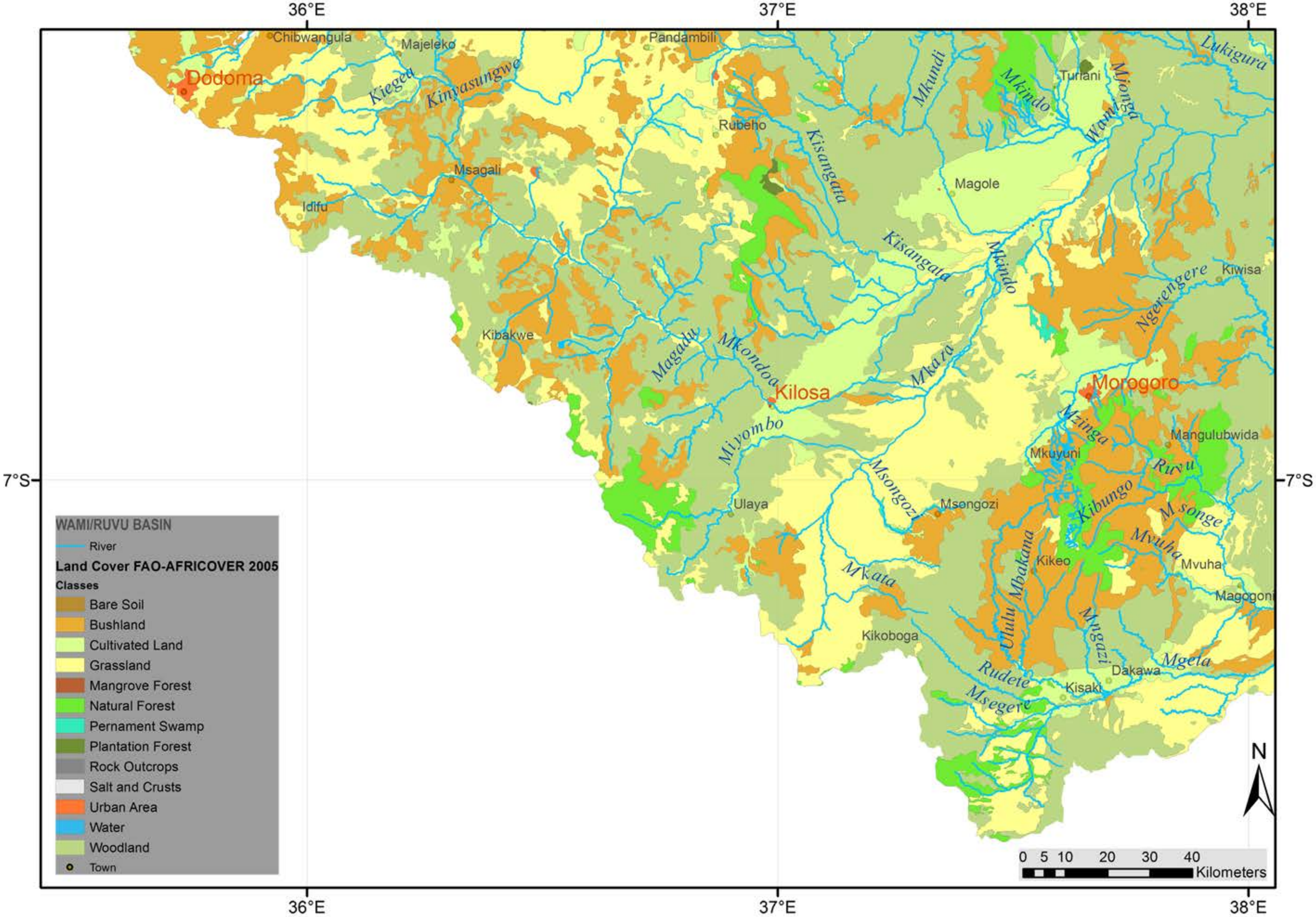
Data Source: AFRICOVER 2005

Map_1_10_C: Land cover in eastern Wami/Ruvu Basin



Data Source: AFRICOVER 2005

Map_1_10_D: Land cover in southern Wami/Ruvu Basin



Data Source: AFRICOVER 2005

Section 2:

Physical features, topography and lithosphere

2.1 Physical landscape

The Wami and Ruvu rivers originate in the biodiversity rich, perpetually cloudy Eastern Arc Mountain ranges of Tanzania, and flow across fertile agricultural plains and grassland savannahs to the Indian Ocean. Located between 5°–7°S and 36°–39°E, the two basins extend from the semi-arid Dodoma region to the humid inland swamps in the Morogoro region towards the coastal cities ending in Bagamoyo district. The basins encompass an area of approximately 43,000 km2 and 18,000 km2 respectively, spanning an altitudinal gradient of approximately 2260 meters (IUCN 2010).

The eastern, ocean-facing slopes of the Eastern Arcs receive the highest rainfall in the basin, which is trapped by the tropical montane cloud forests that remain in the higher reaches (>1200 m) on account of being protected as Forest Reserves. Tributaries of the Ruvu arise in the Ulugurus (highest point 2630m) with human settlement and agriculture right upto the forest boundary. Tributaries of the Wami arise in the Ngurus (highest point 2400 m), Nguu

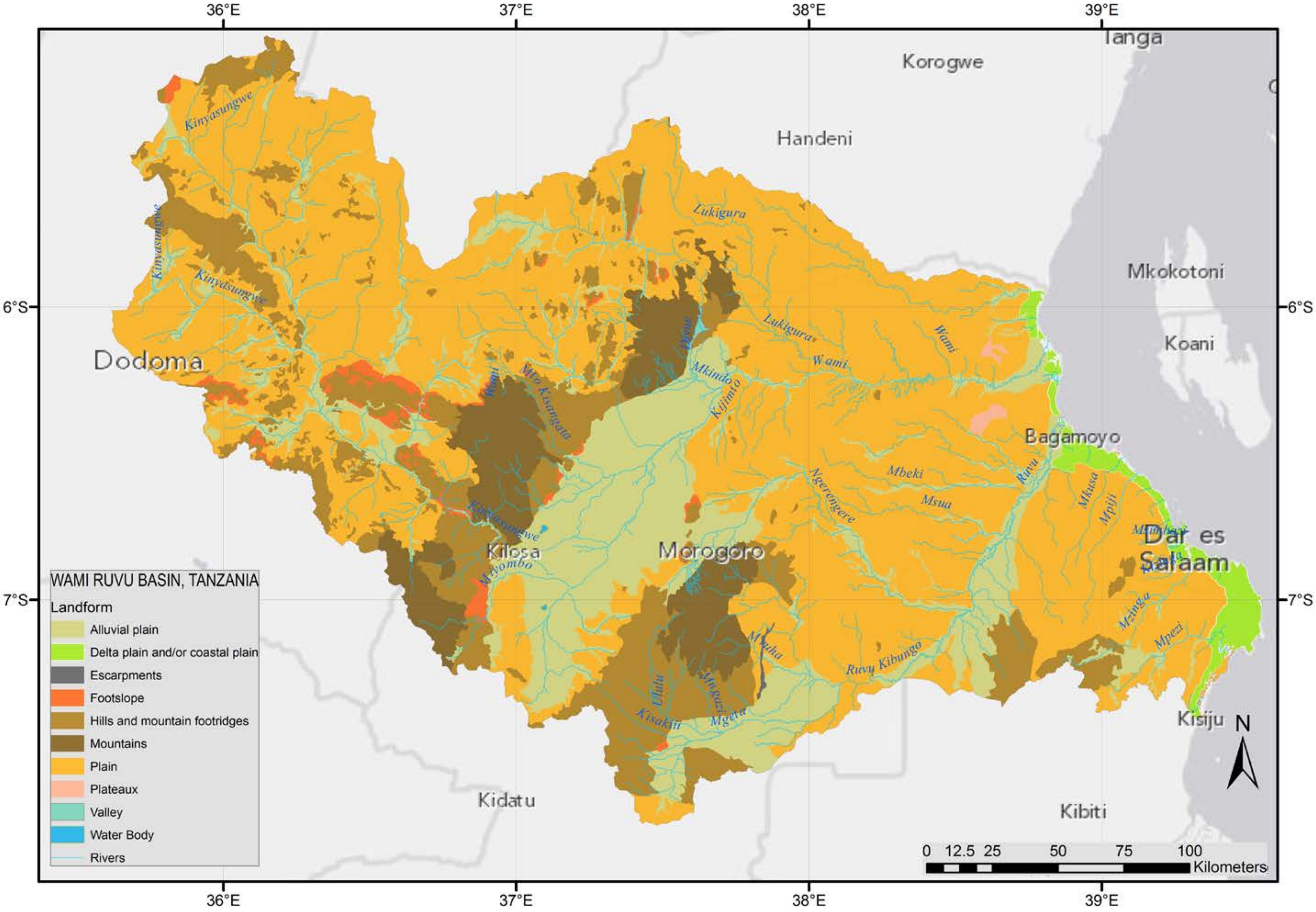

Cloud forest covered mountains around 1200-1400 meters above sea level in the Ulugurus.


Stream arising from the Nguru mountains, Mkindo catchment, Wami basin.

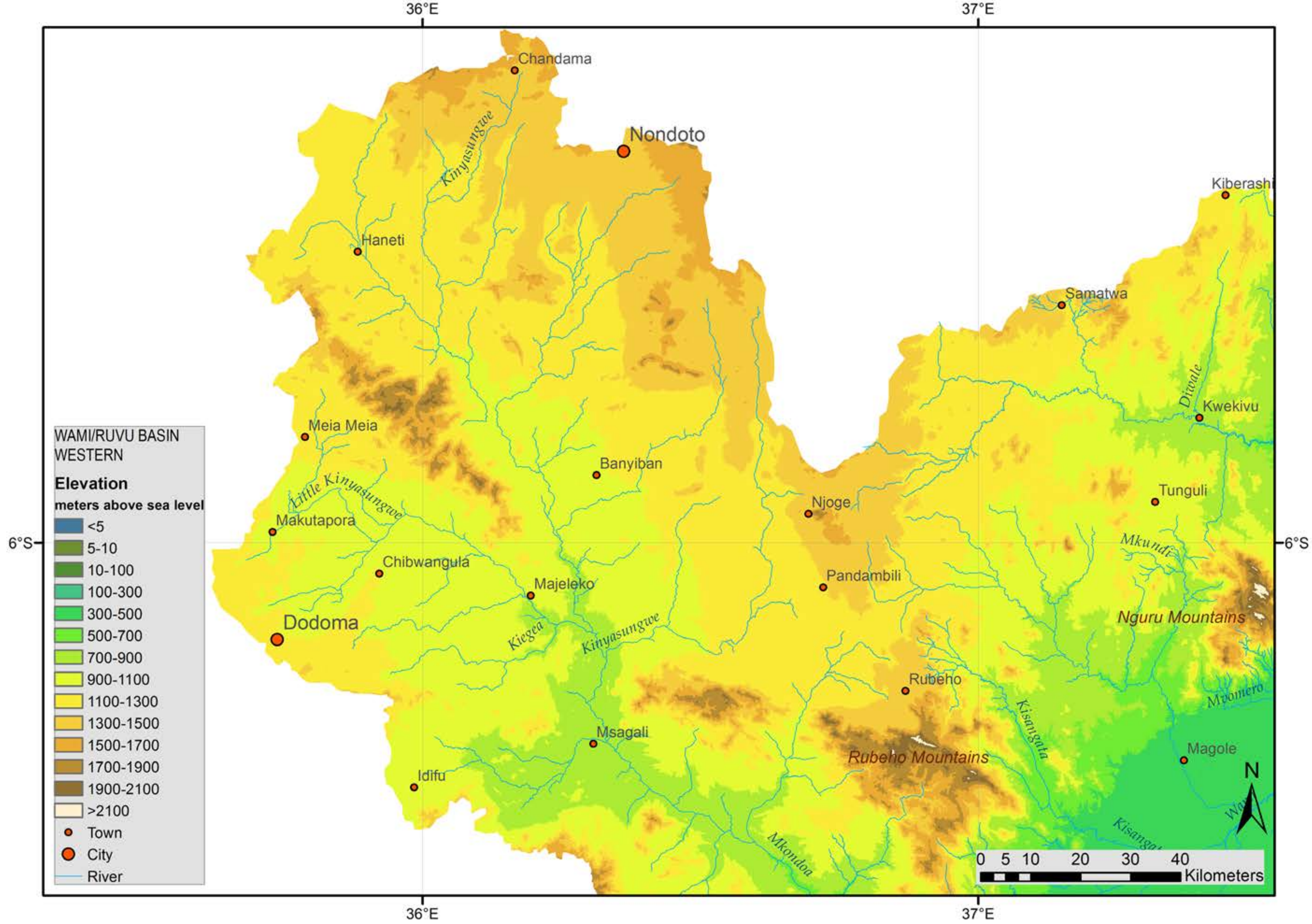

Sisal plantation in the flat lowlands with the Uluguru mountains in the background.


Mangroves and coconut palms along the Indian Ocean coastline in Bagamoyo district.

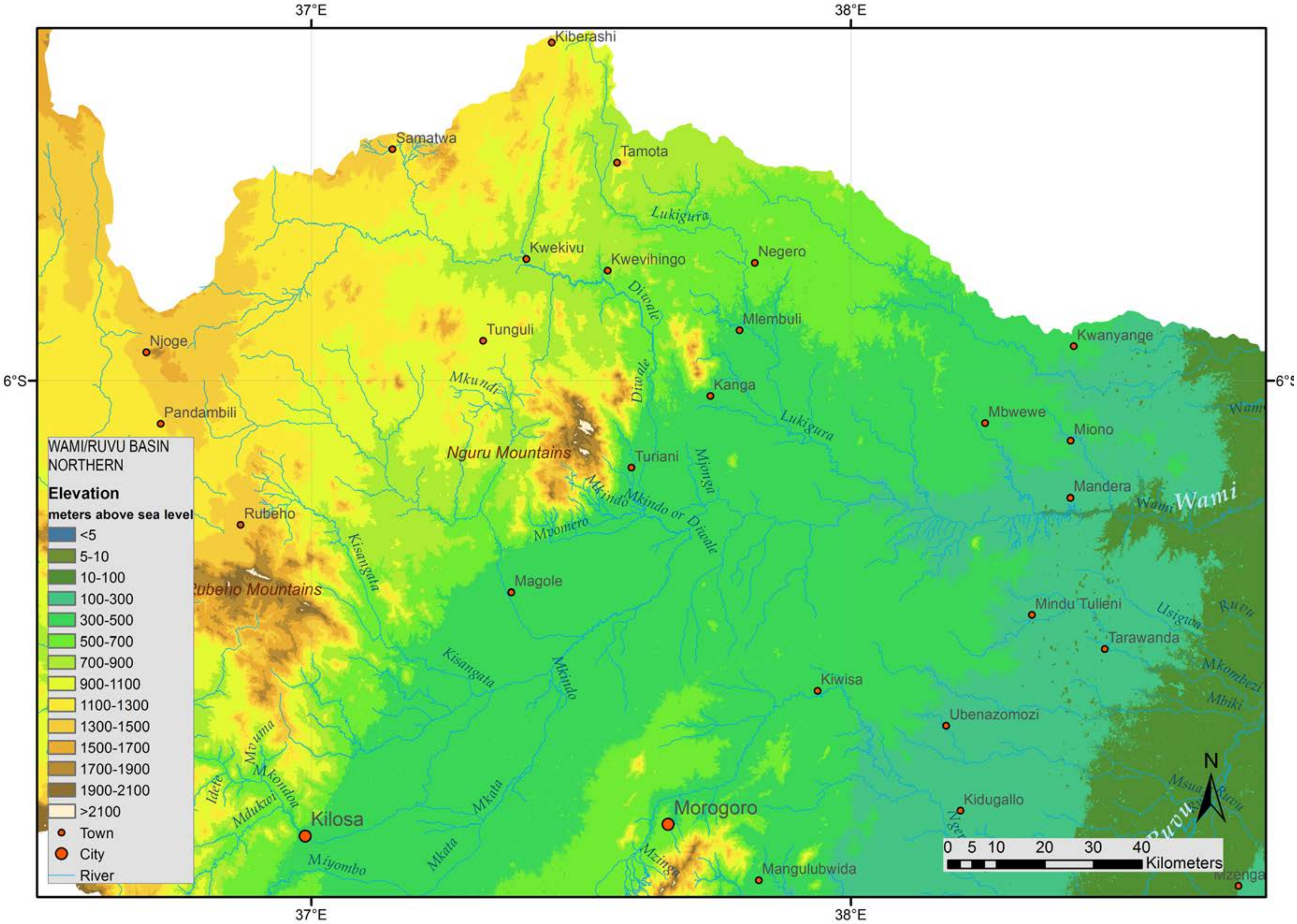
Map_2_1: Landforms of the Wami/Ruvu Basin



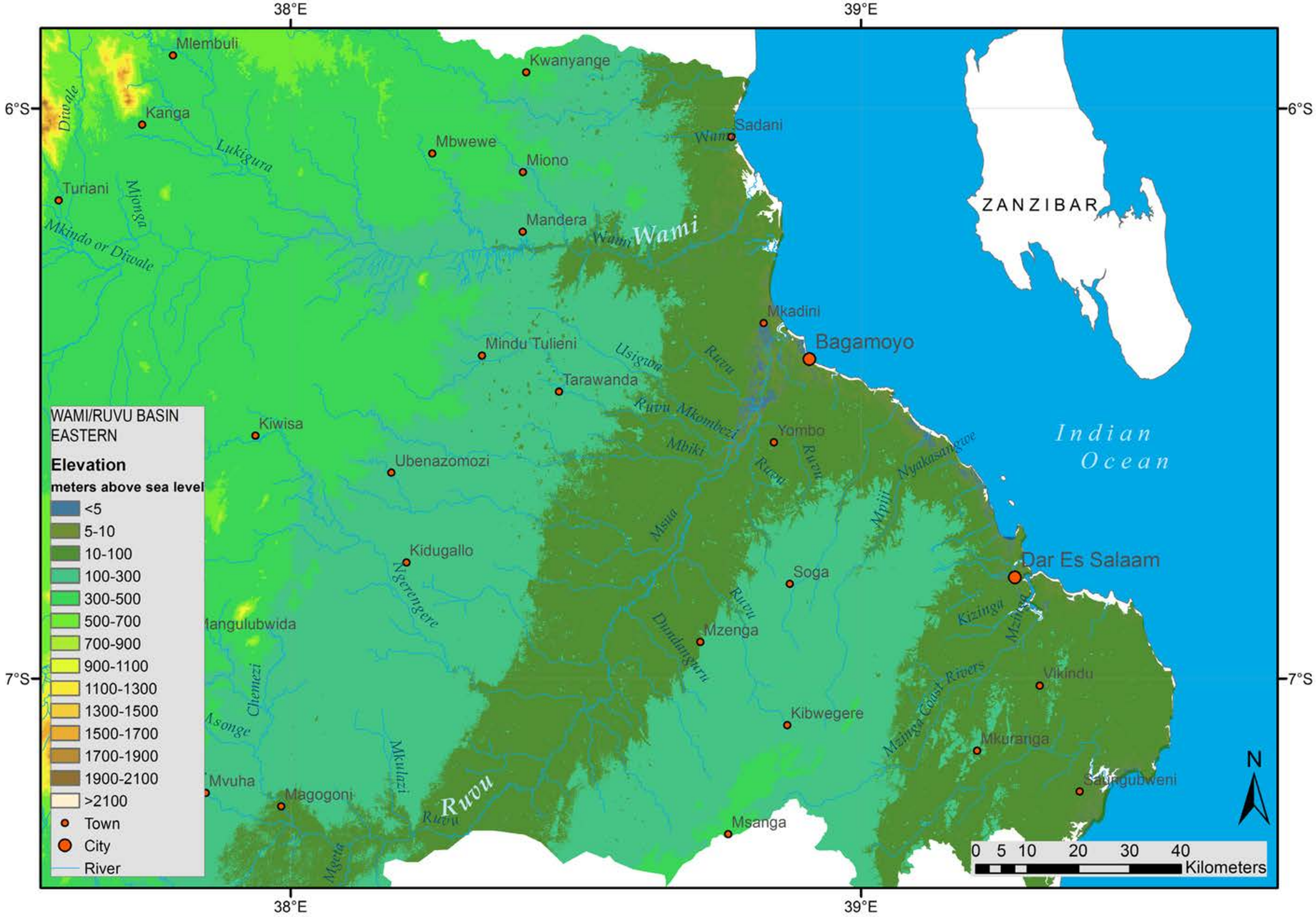
Map_2_2: Western Wami/Ruvu Basin topography



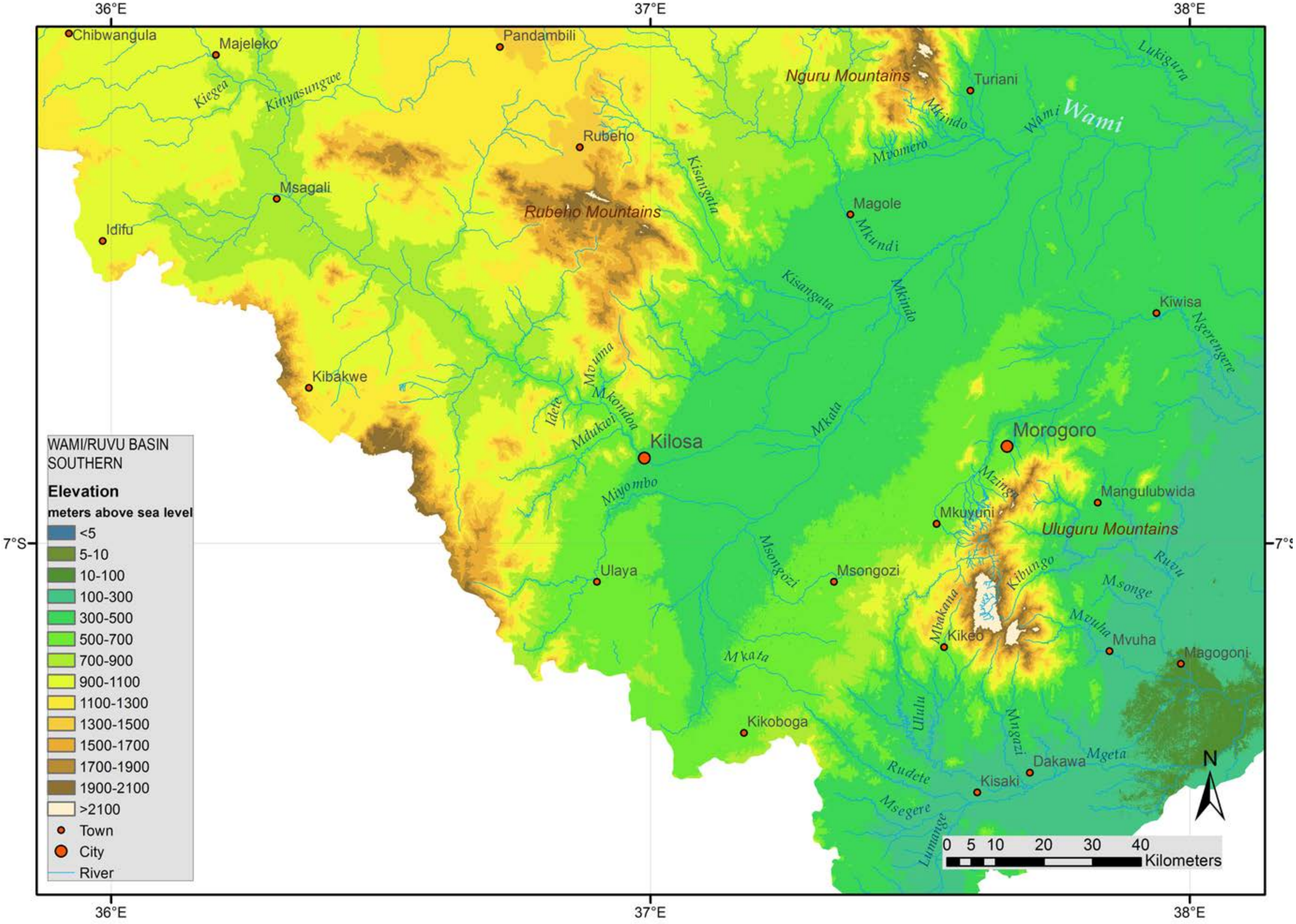
Map_2_3: Northern Wami/Ruvu Basin topography



Map_2_4: Eastern Wami/Ruvu Basin topography



Map_2_5: Southern Wami/Ruvu Basin topography



Map_2_6: Subcatchments of Wami/Ruvu Basin

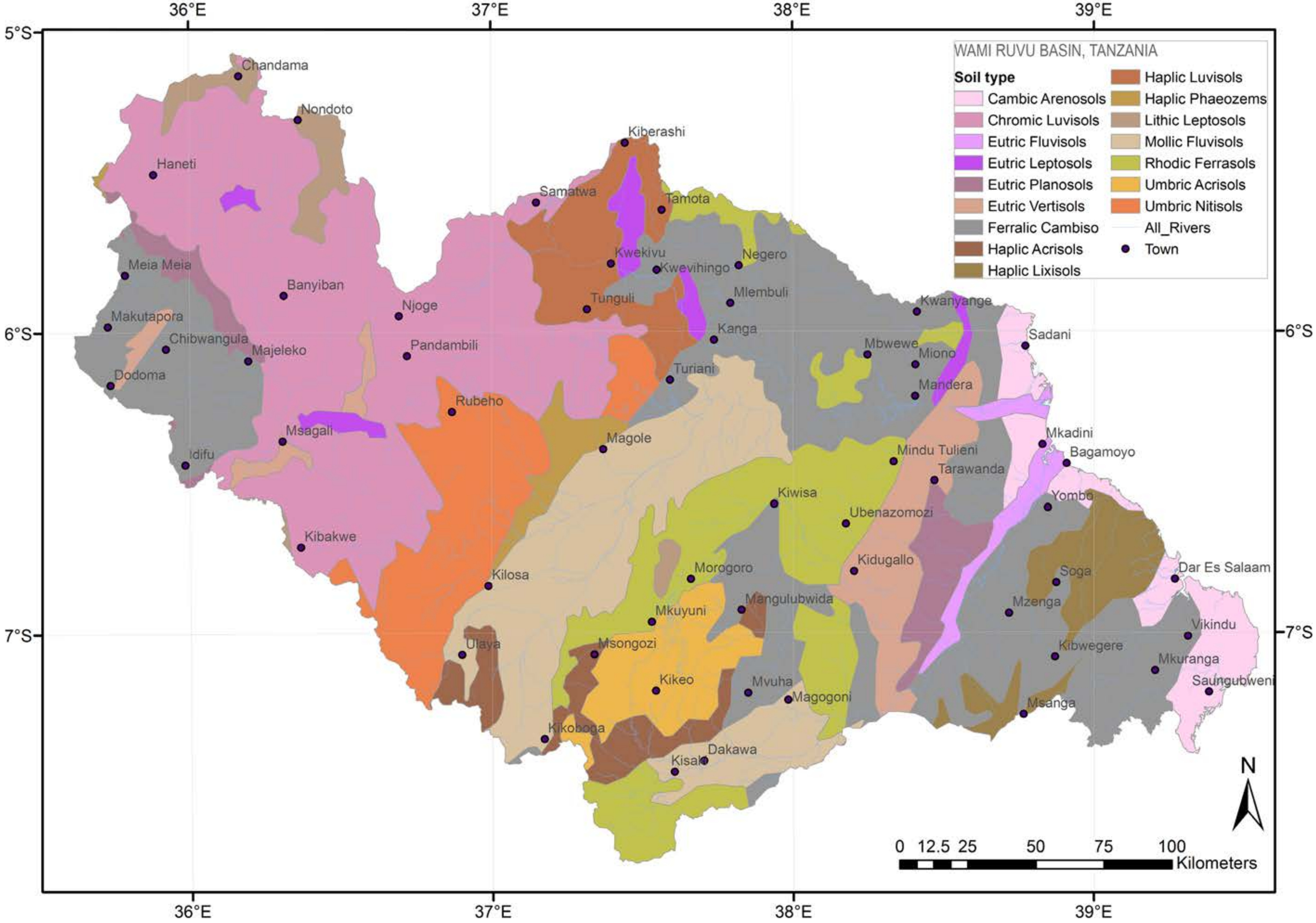
2.2 Geology of the Wami Basin

The Wami basin's sediments are comprised of diverse lithologies derived from cratonic granitoids of the Precambrian age in the West, highly metamorphosed rocks of the Orogenic belts in the central area of the basin and a Neogene deposit in the East. The basin has been affected by faults, causing terrace and cascade flows at the western boundary of the coastal plain. The rivers are flowing in the West-South trending fault zone form a gorge before entering the coastal plains. The Wami River drains the cratonic shield rocks in the Dodoma area, Usagarani and Quaternary Sediments in Morogoro Region and the Jurassic, Cretaceous, Tertiary and Quaternary sediments in the coastal region. The cratonic rocks composed of granite, basic and ultra-basic are the oldest plutonic rocks in the region. These rocks exist on isolated hills and mountains in the Dodoma area. The Usagara systems (orogenic belt) are the oldest metamorphic rocks composed of gneiss and dolomite marble. The Jurassic and Cretaceous sequence are thin beds of sandy limestone and calcareous limestone, which alternate with thicker beds of mudstone marls. The South West – East West trending plain consists of quaternary sediments, which are alluvial sediments deposited by rivers. Above 200 m the plains consist of mbuga soils. The coast has beach ridges, salt-pans and estuarine mangrove swamps. The Wami River forms a wide deltaic deposit of about 20 km that extends south from Saadani centered at Ras Utondwe, part of which is included in Saadani National Park.

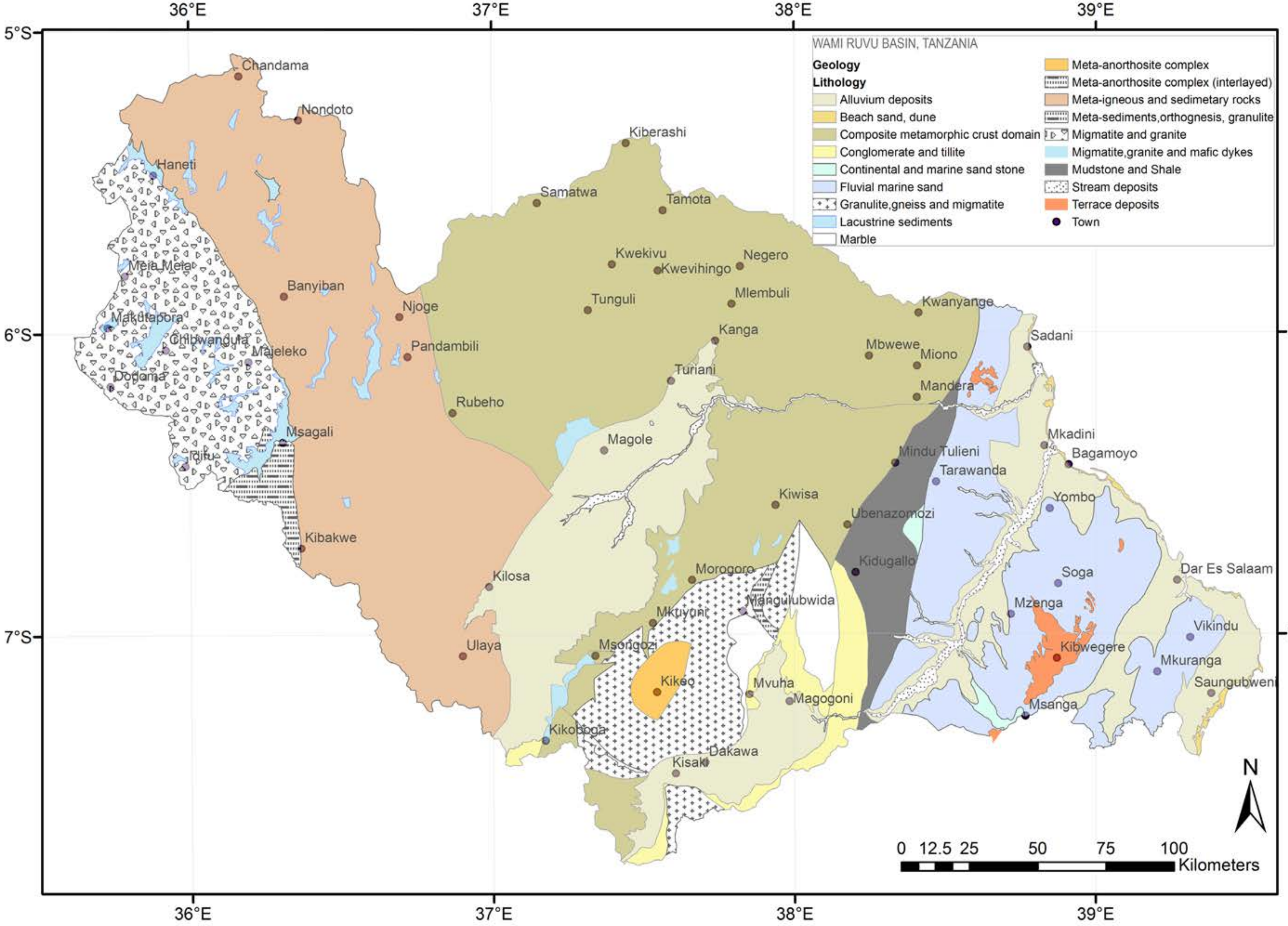
2.3 Geology of the Ruvu Basin

The geology of the Ruvu sub-basin can be categorized into the following five major divisions: Precambrian, Karoo, Jurassic, Cretaceous, Tertiary and Quaternary rocks. Precambrian rocks, which are mainly meta-sedimentary, occur mostly in the Uluguru Mountains and in the western part of the Ngerengere sub-basin and can be divided into three major lithological groups: acid gneisses, granulites and crystalline limestone. The last has been thrust and uplifted by the upward movement of the basic gneisses, thus giving rise to distinct fault zone in the rocks (JICA 1994). The Karoo rocks that occupy the southeastern area of the Uluguru Moutains consist mainly of sandstone and shale, which was originally deposited in shallow fresh to brackish water. Their ages may vary from Permian to Triassic. Jurassic rocks occur in the eastern margin of the Uluguru Mountains and elevated rolling hills between the Ruvu and Wami rivers. They consist of course sandstone, mudstone and oolitic limestone deposited under the marine environment. Cretaceous rocks, which lie on the elevated rolling hills, consist of clay, shale, calcareous sandstone, sandy limestone and mudstone. Sediments of Tertiary and Quaternary ages (youngest strata in the basin) occur in the catchment area of the Ngerengere River near the Morogoro Municipality and in the elevated rolling hills and floodplains along the Ruvu River and extend up to Dar es Salaam. The Tertiary deposits consist of sandy clay, clayey sand with lenses of pure sand or clay, gravel and calcareous fragments. The Quaternary deposits were formed in the alluvial fan and are subject to swampy condition during the wet season; they consist of clay, silt, sand and rarely gravel. Similar to the Wami estuary. the Ruvu estuary has alluvial mud deposits. Source: IUCN 2010

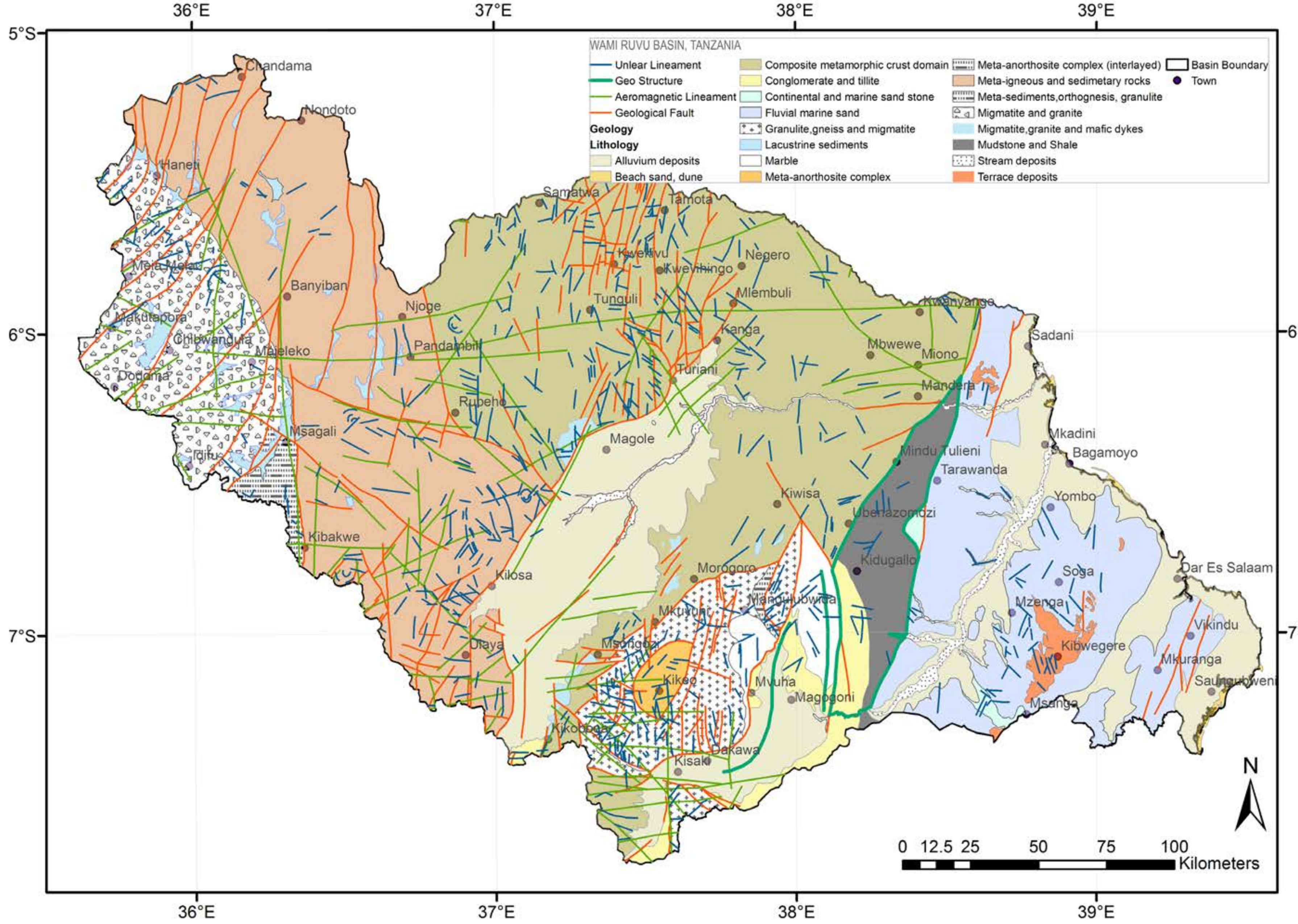
Map_2_7: Soil classification in the Wam/Ruvu Basin



Map_2_8: Geology of the Wam/Ruvu Basin



Map_2_9: Geological lineaments in the Wam/Ruvu Basin



Section 3:

Ecosystems: forests, wetlands and biodiversity

3.1 Forests, wetlands and water resources

Streams in forested watersheds flow longer, cooler and clearer (less turbid) than in deforested watersheds. In addition, the forest regulates the flow of water and runoff. The availability of water in a watershed not only depends upon rainfall but is also affected by the presence of forest cover. Native tropical evergreen cloud forest occuring in the higher reaches (> 1200m) of the Eastern Arc mountains has a thick multi-layered canopy that traps moisture from clouds present year-round. The canopy also intercepts a large fraction of the rainfall thereby allowing intercepted rainwater to infiltrate through to the litter layer, soil and recharge groundwater (Bruinjzeel & Hamilton 2000). This groundwater is the source for springs and streams downhill. The canopy also protects the thin forest mineral soil from erosion. Removal of forest cover has been thus linked to higher surface runoff during rains and consequently the earlier drying up of springs and streams in the dry season (eg. Munishi & Shear 2005, .Giambelluca & Gerhard 2011).

Further lower in the foothills are deciduous woodlands which have similar water harvesting functions as montane forests. In the lowlands at the base of the foothills lie extensive wetlands which store vast amounts of water during the rainy season from catchment runoff , which then feeds downstream rivers in the dry months. In addition to water storage, wetlands also trap sediment and nutrients as the water flow is slowed down by wetland vegetation which allows for sediment deposition and nutrient uptake by plants, which forms the base of the highly productive wetland ecosystems.

Forest cover has been declining all over the Wami and Ruvu basins over the past couple of decades. The largest loss has been in the lowland miombo woodlands, where tree-cutting for charcoal and forest clearance for agriculture has been rapid and extensive. The Eastern Arc mountains in comparison have had less forest loss over the same period, on account of most of the remaining forests in these mountains being protected as forest reserves. Wetlands have been drained for agriculture. It is important to protect the remaining wetlands to preserve their role in water storage, flood protection, ensuring river-flow in dry months and water quality, apart from their provision of fisheries and small-scale paddy. Protection of forests and wetlands requires the cooperation of diverse stakeholders, from local communities, nongovernmental organizations to the Ministry of forests, social welfare, agriculture and water. This is because, apart from forests providing the most economical manner of buffering watersheds from the vagaries of climate change by ensuring water availability, they also support livelihoods and are globally known for their endemic biodiversity. More information on forest ecosystems and conservation efforts are available at the website of the Eastern Arc Mountains Conservation Fund:
http://www.tfcg.org/easternArcMountains.html

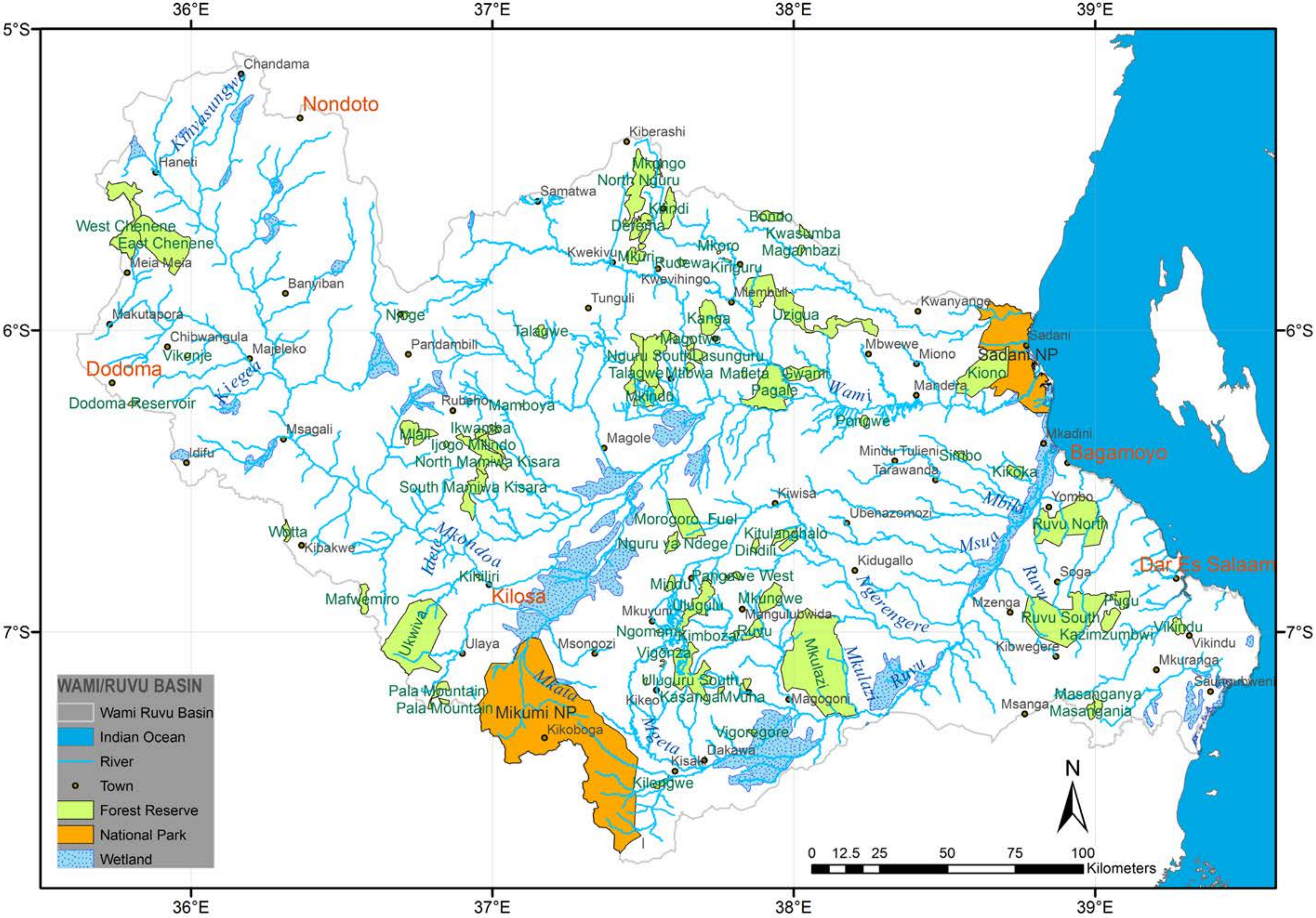
Maps of forest and wetland ecosystems allow water resource planners and managers to:

Visualize locations and extent of these natural water harvesting systems along with the river network.

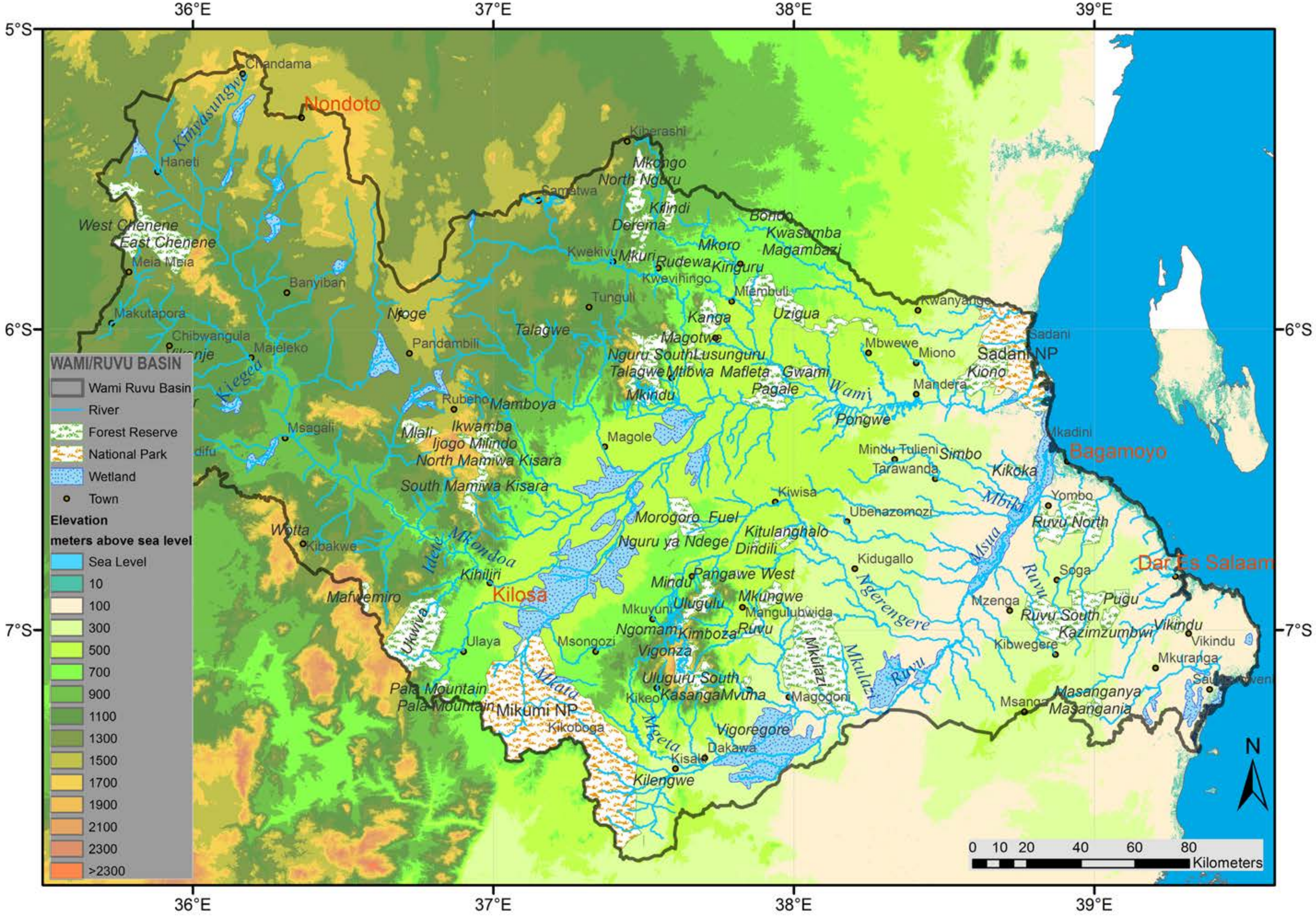
Identify stakeholders and communities in the vicinity for involvement in protection /management.

Set up rainfall, flow and water quality monitoring stations in locations close to forests/wetlands to better understand their role in catchment hydrology in the Wami/Ruvu Basin.

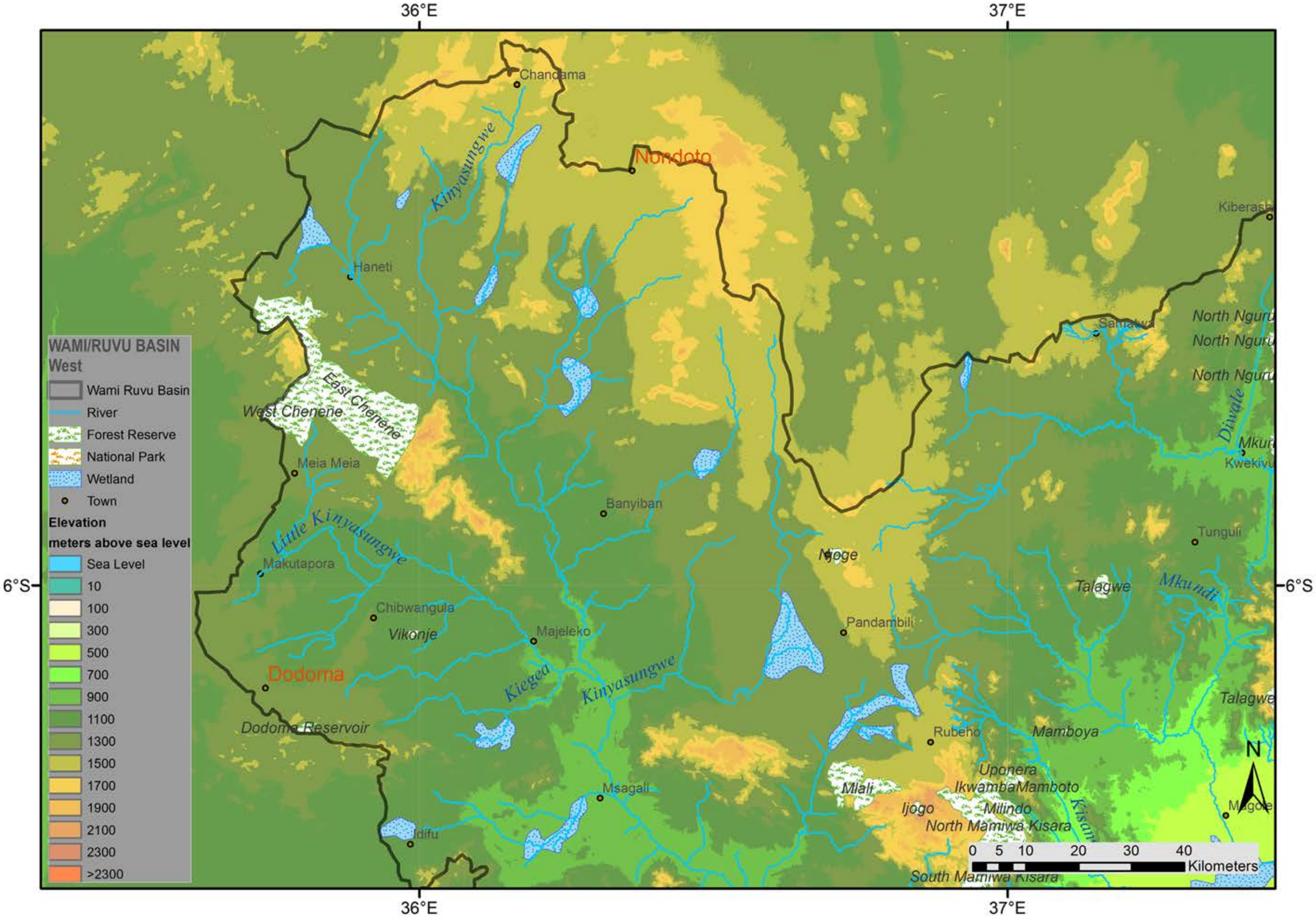
Map_3_1: Forest reserves, national parks and wetlands in the Wami/Ruvu Basin



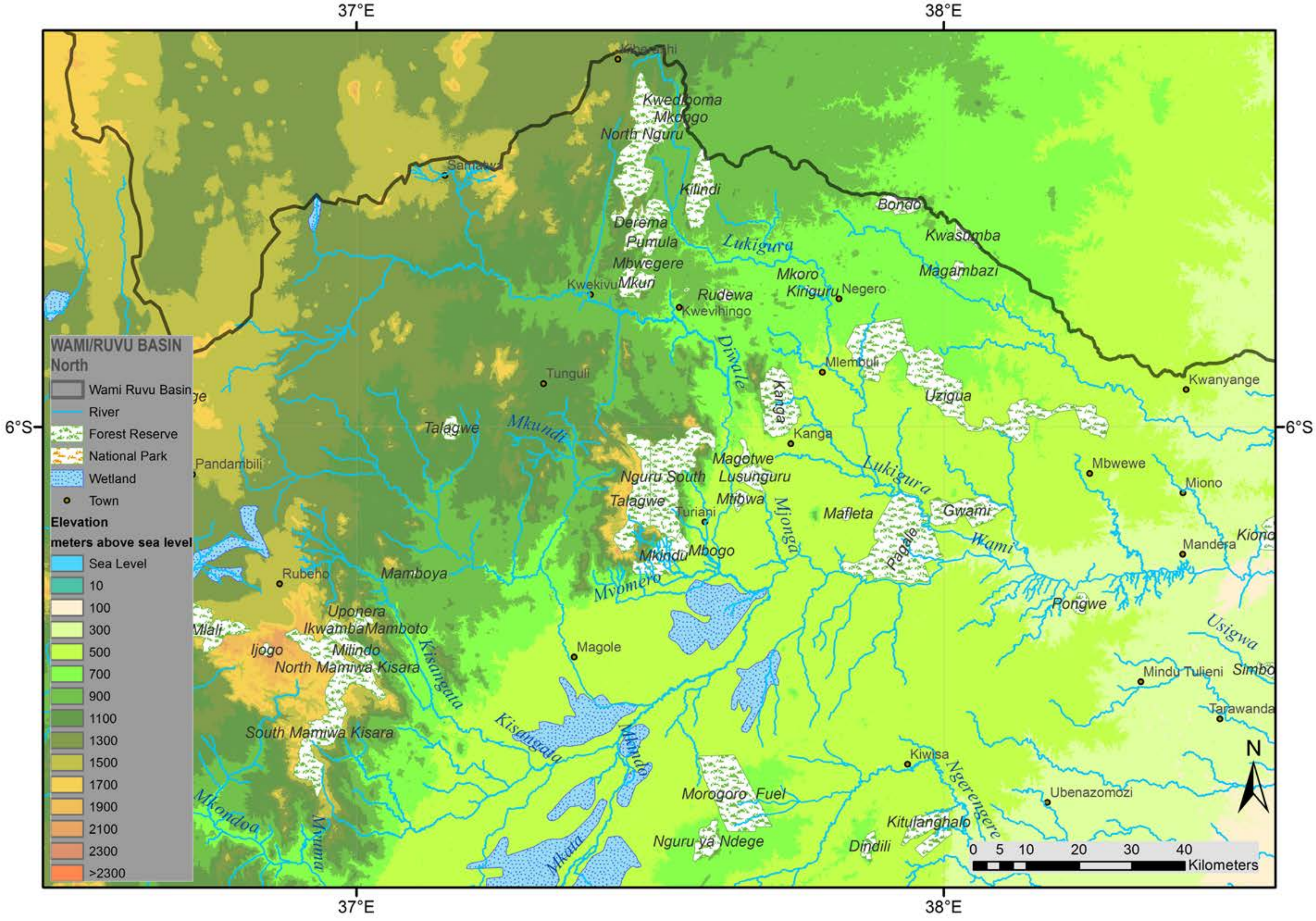
Map_3_2: Forest reserves, national parks and wetlands with topographic map



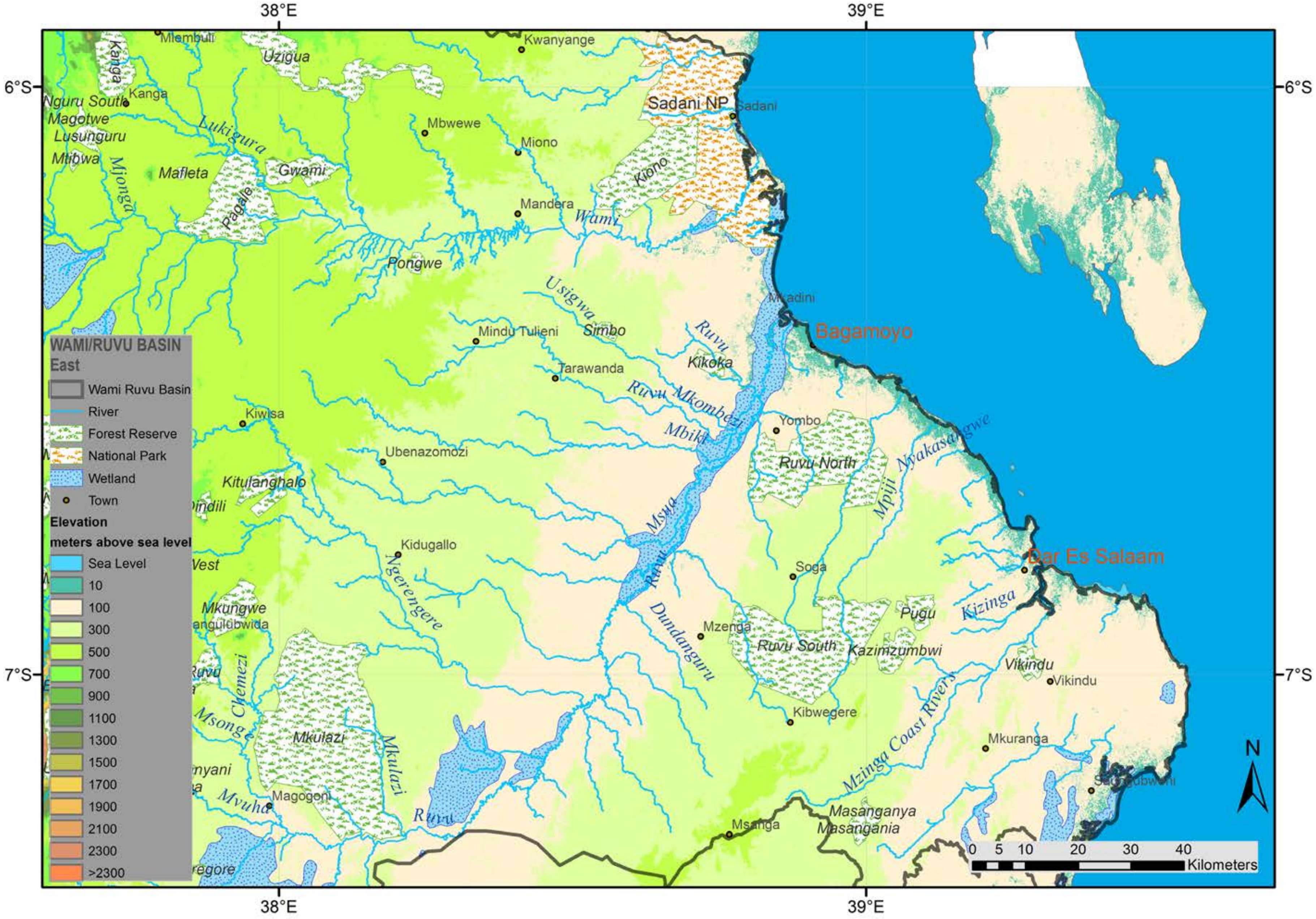
Map_3_3: Forest reserves, national parks and wetlands in the western Wami/Ruvu Basin



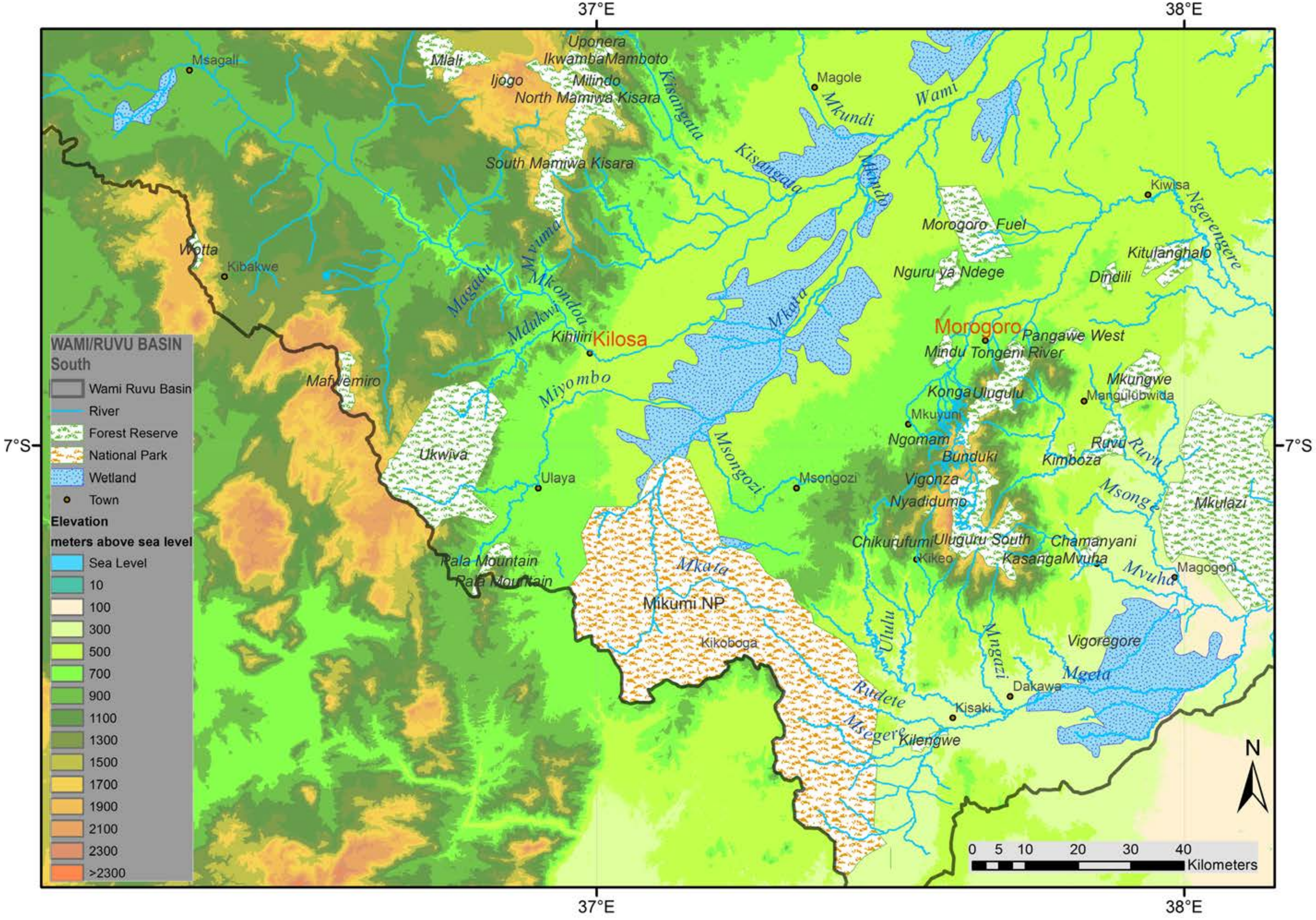
Map_3_4: Forest reserves, national parks and wetlands in the northern Wami/Ruvu Basin



Map_3_5: Forest reserves, national parks and wetlands in the eastern Wami/Ruvu Basin



Map_3_6: Forest reserves, national parks and wetlands in the southern Wami/Ruvu Basin



3.2 Ecosystems and biodiversity

The preservation of biodiversity helps maintain healthy ecosystems, which in turn sustain human life by providing natural-resource based livelihoods, water, medicines and flood-control, to just name a few. A stunning variety of ecosystems and biodiversity exists within the Wami and Ruvu basins. These are notably the following:

1. Eastern Arc Mountains (Ngurus, Nguu, Ukagurus, Ulugurus and Rubeho mountains): this is a chain of ancient mountains covered by rainforests and grasslands in Tanzania and Kenya have several thousand species of flora and fauna, with some of the highest concentrations of endemism on Earth, that is, plants and animals not found anywhere else (Burgess et al 2007). New species are still being discovered. Tropical montane cloud forests have survived on these mountains for over 30 million years, and were once connected to the forests of the Congo Basin and West Africa, based on the presence of common flora and fauna. For instance, the Ruvu river system is one of the only two eastward flowing rivers in Africa (another being Rufiji/Great Ruaha river system) to have a fish species (*Citherinus* sp), a genus otherwise confined to West Africa or westward flowing rivers. The Eastern Arc Mountains Conservation Fund has a comprehensive list of information resources at http://www.easternarc.or.tz/.

2. Miombo woodlands and savanna—these are the grasslands with *Acacia* and *Brachystega* woodlands with the vast diversity of wildlife that East Africa is world-reknowned for.

3. Estuarine forests, coastal ecosystems and coral reefs – these coastal environments provide nurseries for marine fish that constitute the primary protein source for coastal communities. Coral reefs, well-preserved beaches and clear seas also generate increasing revenue from tourism.

Diversity of forest types in the Wami/Ruvu Basin is directly related with natural water availability


Lowland deciduous miombo woodlands


Savanna grasslands interspersed with woodlands


Tropical montane evergreen cloud forest in the Eastern Arc mountains (1200-2000m).


Wetlands

Issues for concern

Numerous threats threaten these ecosystems: habitat loss, poaching and hunting, exotic species introductions, climate change and the change in hydrological regimes that occur due to high rates of water abstraction from rivers, deforestation and sedimentation/water pollution. The IUCN lists around 110 amphibians and 22 species of reptiles that are threatened with extinction in the Wami/Ruvu Basin (IUCN 2012).

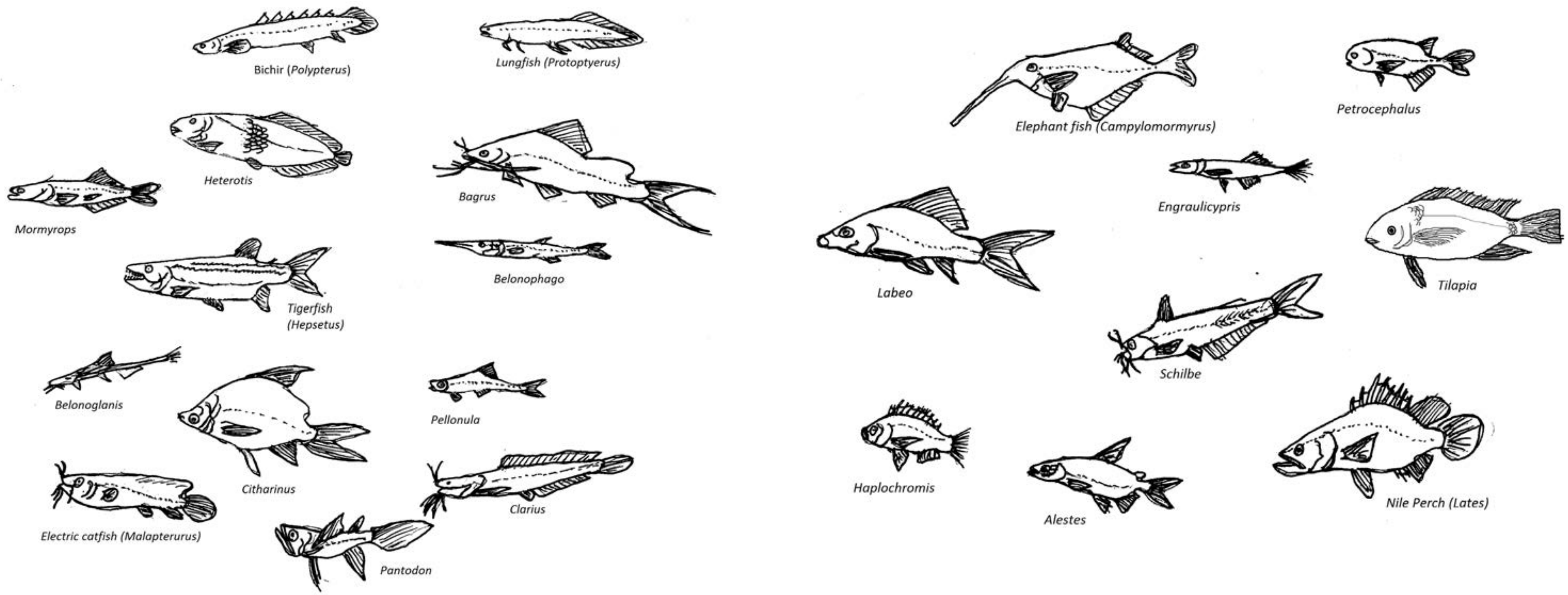
From a water resource management perspective, it is necessary to know the seasonal hydrological regime of different ecosystems, so as to be able to maintain water flow and quality to maintain these ecosystems. This is especially significant for lowland ecosystems such as wetlands, estuaries, gallery forests and savanna woodlands that are directly impacted by water abstractions for other uses. Montane forests on the other hand are more impacted by deforestation and climate change.

Ecosystems and biodiversity

Aquatic ecosystems are the first to be directly affected by water resources management; in turn, they also play a large role in naturally maintaining water quality. Aquatic habitats include forested headwater streams, medium-sized rivers and their tributaries, mangrove forest-covered estuaries, small lakes, permanent swamps, dambos and seasonal floodplains. Vegetation adjacent to and within the freshwater systems consists primarily of a coastal mosaic including large areas of miombo woodland, coastal dry forest and coastal scrub, riparian and swamp forests, floodplain vegetation, and mangrove forests (Oyugi & Kashaija, 2013). Swamp and riparian forest trees include *Pandanus rabaiensis, Baikiaea insignis, Syzygium cordatum, Ficus verruculosa, F. trichopoda, V*oacanga *thouarsii, Raphia farinifera* and *Parkia filicoidea*. *Cyperus papyrus* also grows in permanent swamps lining the rivers, often in association with *Phragmites* spp. and *Nymphaea capensis*.

Fish Fauna

Characins, anguillid eels, rivulins, cyprinids, gobies, and mochokids are the groups with the largest number of species in coastal East Africa (Oyugi & Kashaija, 2013). About thirty percent of the nearly 100 described fish species are endemic. Some of the endemic resident fish species in the Ruvu River Basin are *Nothobranchius foerschi, Alestes stuhlmanni* and *Oreochromis urolepis*. while vulnerable or near endangered species include *Distichodus petersii, Schilbe moebiusii, Opsaridium microcephalum, Nothobranchius lourensi, Nothobranchius foerschi, Nothobranchius flammicomantis* and *Nothobranchius annectens*(IUCN Red List). Two more fish species (*Petrocephalus catostoma and Parakneria spekii)* are listed as rare and endangered under the Tanzania national fish conservation rankings.



Line drawings of some characteristic fish groups from East African freshwater bodies.

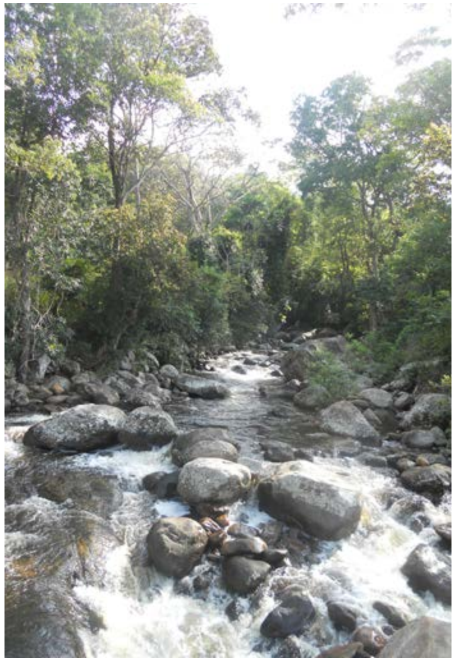
3.3 Riparian / gallery forests and biomonitoring of stream ecosystems

Gallery forests:

Trees and other natural vegetation on streambanks are well known to maintain stream ecosystems by providing shade, food and soil stabilization. Oftentimes they are also the only remaining forests and natural habitat on the landscape otherwise cleared for agriculture. Thus gallery forests provide shelter for migratory birds and other wildlife. Protection of riparian forests are critical to both maintaining aquatic biodiversity as well as provisioning natural resources in the form of fuelwood, fodder, timber and medicinal plants for local communities. Gallery forests along the Wami and Ruvu rivers are rich in endemic plants, along with a number of riparian plant species with high conservation importance such as *Khaya anthotheca, Milicia excelsa* and *Uvariodensdron kirk*ii that are listed in the IUCN threatened and endangered list.

Aquatic Macroinvertebrates—biological water quality indicators:

Aquatic macroinvertebrates (insect larvae that live in water) occur under streambed stones sheltered from the swift stream current. They are an important component of stream ecosystems, as some of them shred and feed on leaf litter while others are predatory. Most aquatic invertebrates are in turn an important food source for fish. Deforestation, road building and farming without soil conservation in the surrounding watershed results in soil erosion that enters streams and settles down on the stream bottom, covering the spaces underneath rocks, thereby removing habitat for aquatic macroinvertebrates, with attendant negative effects upon the ecosystem and water quality. Aquatic invertebrates are thus used widely as indicators of stream health, the capacity of a stream to support life as well as water quality. While there is information on aquatic macroinvertebrates in East African streams, (McClanahan and Young 1996), a biomonitoring guide based upon them (such as the South African Scoring System) remains to be created for Tanzanian rivers. The Environmental Flow Assessment of the Ruvu River identified 5 families (Perlidae, Tricorythidae, Heptageniidae, Oligoneuridae and Polymitarcyidae) as being highly flow-sensitive.



Riparian Forest: Gallery forest adjoining the Mkindo river, Wami River Basin.

A damselfly larvae on the streambottom of Mkindo river, Nguru mountains.

An example of a well-known insect, a dragonfly whose larval and nymph stages are aquatic. Dragonfly nymph and adult.

Biomonitoring of streams for water quality and catchment ecosystem health: Lifting a riverbed stone to examine for aquatic macroinvertebrates (insect larvae) underneath.

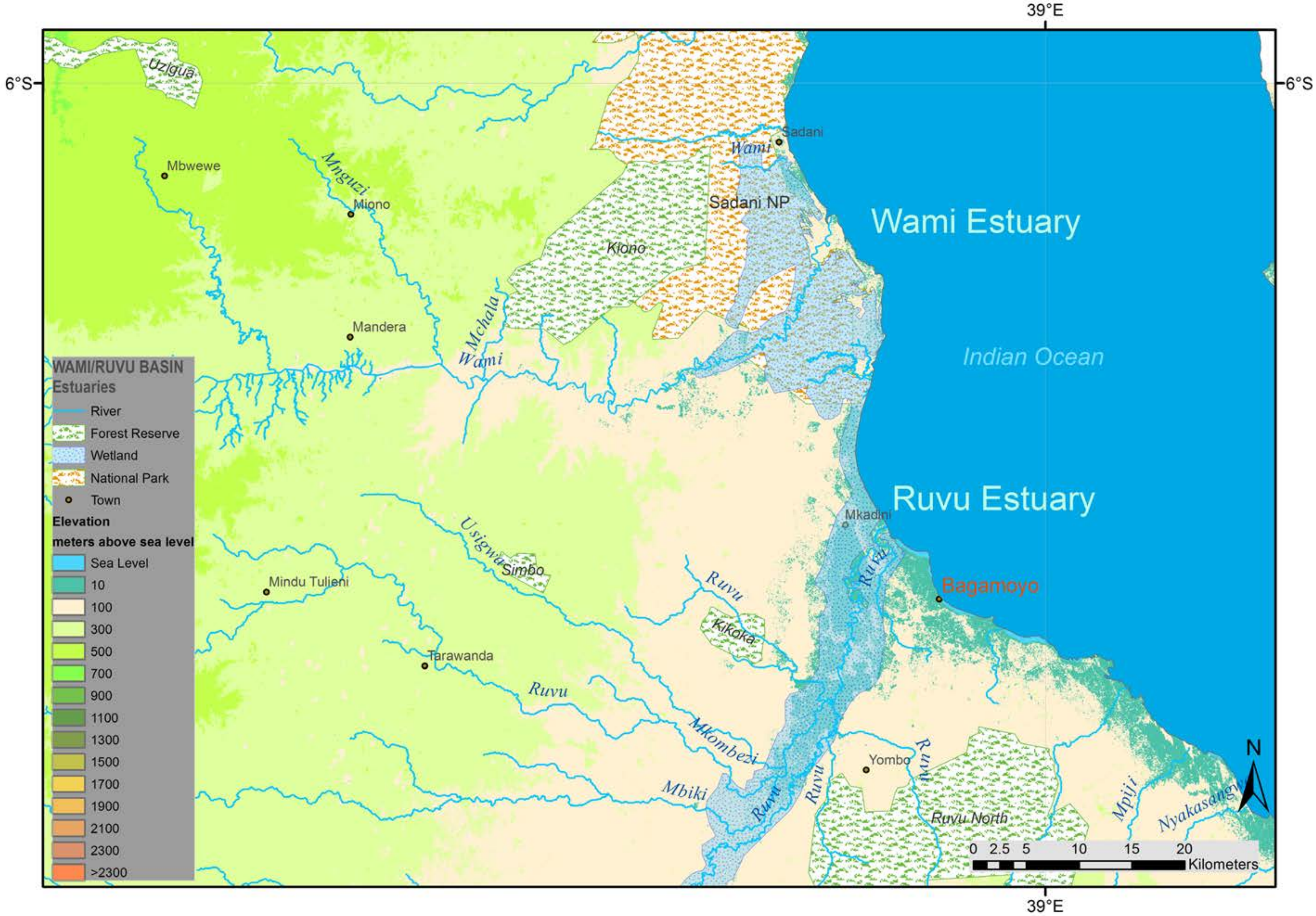
3.4 Estuaries

Both the Wami and Ruvu rivers form large estuaries where they flow into the Indian Ocean. Estuaries support extensive mangrove forests that provide the last shelter for wildlife on a landscape that has been otherwise cleared of forests for agriculture and settlement. Coastal communities also depend upon mangrove forests for their livelihoods; mangrove poles have been used for boat-building and exported around the Indian Ocean for centuries. Mangrove forests also protect coastlines against wave erosion and storms. Shallow marine areas of the estuaries have seagrass beds that provide critical habitat for marine fish and invertebrates and are nurseries for coastal fisheries. Estuary ecosystems depend upon receiving adequate freshwater inflow from rivers that vary seasonally. This freshwater inflow also resists seawater intrusion into estuaries and shallow coastal aquifers, thereby resisting the salinization of coastal wells. Ensuring that over-abstraction of water from the river does not decrease the inflows to estuaries is a matter for water management.

Wami River Estuary from over the Indian Ocean, looking westwards into Tanzania

Nile crocodile entering the Ruvu River in the estuary.

Map_3_7: Wami and Ruvu estuaries



Ecosystem services from the Ruvu River estuary


Fish market in Bagamoyo with fish caught in the sea near the Ruvu estuary.

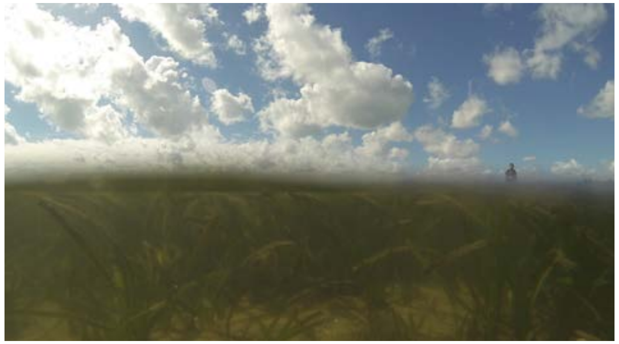

An ngalawa, a sailboat with outriggers, used for fishing in shallow seas, and made entirely out of mangrove poles and wood.


Wildlife in the estuary.

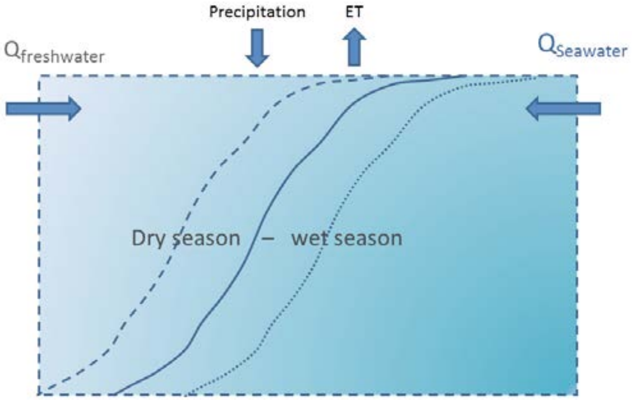

Coastline protection against wave erosion and storms by mangrove *Sonneratia alba.*

3.4.1 Freshwater: the lifeblood of estuaries

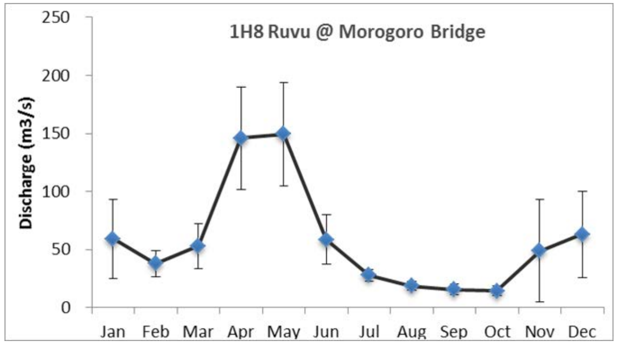
Estuaries have a seasonally changing mix of freshwater via river inflows and seawater, to which the various plant and animal communities have evolved. A decrease in river inflows can lead to higher salinities and temperature, while excessively turbid water can also affect seagrass photosynthesis. Hence, the maintenance of a seasonally-varying freshwater inflow regime into the estuary is necessary.



Seagrass beds in shallow water (< 1 m) need sunlight for photosynthesis. Increasing turbidity can decrease sunlight penetration into the water column and thereby affect seagrass, Seagrasses are also susceptible to temperature and salinity increases



Water balance in an estuary, showing the inputs and outputs. Also shown is the seasonally varying interface of freshwater and seawater, the latter being denser typically slides underneath the freshwater.



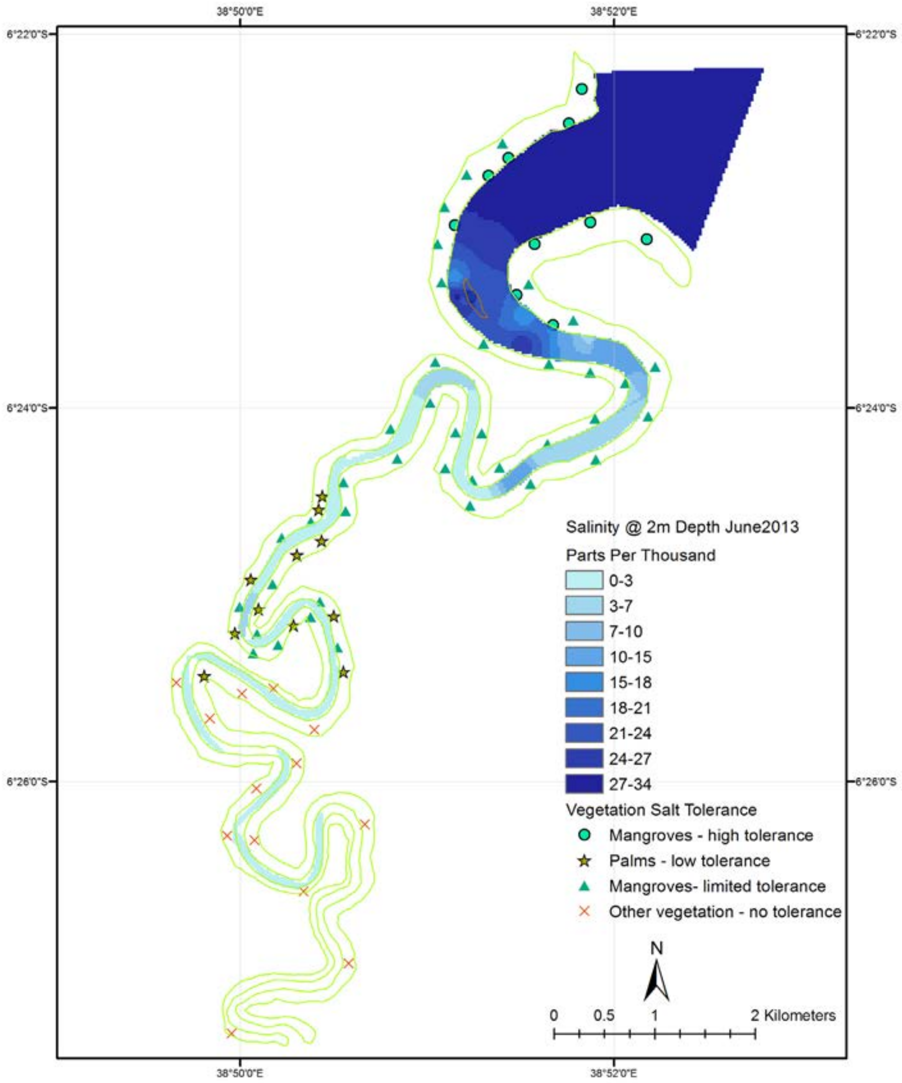
Longterm average monthly flow in the Ruvu River as measured at the Morogoro Bridge station that is nearest to the Ruvu estuary, about 45 km upriver from the estuary mouth.

Preserving the estuarine ecosystem requires maintaining the seasonally-varying salinity regime in the estuary by maintaining the naturally occuring seasonal freshwater inflow from the river into the estuary. Working out this seasonal flow regime requires yearlong salinity data and modeling using a water balance approach (above center); alternatively, long term flow data in the river, such as that measured on the Ruvu River at the Morogoro Bridge station (above right) can indicate the approximate target monthly flows to be aimed for, since communities in the Ruvu estuary were found to still thrive on a recent rapid assessment (GLOWS-FIU, 2014).

3.4.2 Mangroves: sentinels of salinity conditions in tropical estuaries

Trees along riverbanks are long-term indicators of the salinity regime in the estuary and river upstream. Mangroves are the only trees able to tolerate salinity; hence the transition from mangroves to *Phoenix reclinata* palms is an indication of the extent of seawater intrusion upriver from the estuary. Seawater intrudes further upriver during the dry season when opposing freshwater inflows are low, with the furthest inland occurrences coinciding with monthly spring high tides. There are 8 species of mangroves in the Ruvu estuary, each with a different tolerance range of salinity and flooding duration. (Semesi 2001, Richmond 2011)

Map of salinity in the Ruvu estuary (June 21, 2013) in the transition between rainy and dry seasons, with vegetation type. (Saha *et al.* 2014)



Salt crystals excreted out of a white mangrove (*Avicennia marina*) leaf as one example of a salt exclusion mechanism.

Phoenix palms :The appearance of salinity-intolerant *Phoenix reclinata* palms on river banks amidst mangrove forests while traveling upriver in the estuary indicates the presence of largely freshwater conditions throughout the year; thus signifies the extent of seawater intrusion upriver.

Mangrove diversity & salinity/hydroperiod

There are 8 species of mangroves on the Tanzanian coast with different salinity and flood-duration tolerances. (Semesi 2001, Richmond 2011)

Sonneratia alba found along the coastline and estuary mouth is the most tolerant to salinity and tidal inundation with pneumatophores which allow root respiration in flooded anerobic soils.

A diversity of mangroves on a high sandbank - *Ceriops tagal*, *Brugeira gymnorhiza* and *Avicennia marina* (background trees). These are less tolerant to salinity and continual flooding, and hence grow a bit away from the bank with higher sandy soils not waterlogged perpetually.

Rhizophora mucronata is also highly tolerant to salt, with stilt/prop root adaptations. Also seen in center is a *Ceriops Tagal* on the sandbank.

Mudskippers: Air-breathing mudskipper fish (*Perioptha lmus sobrinus*) that enter high sandbanks with the tide.

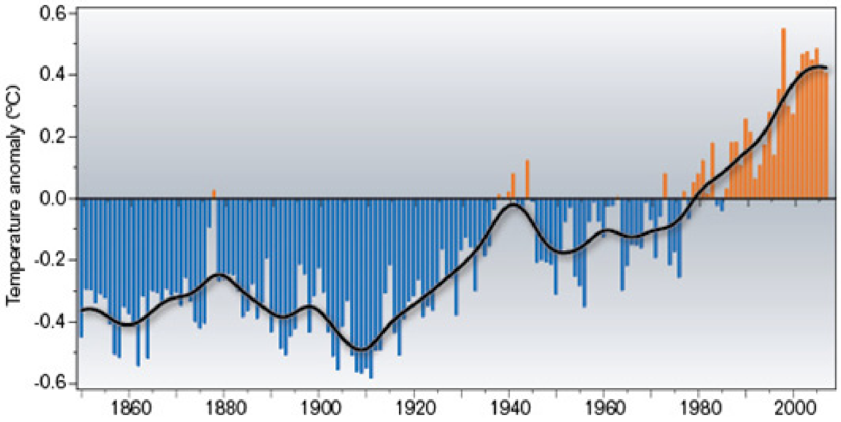
Section 4:

Climate (past trends and future projections)

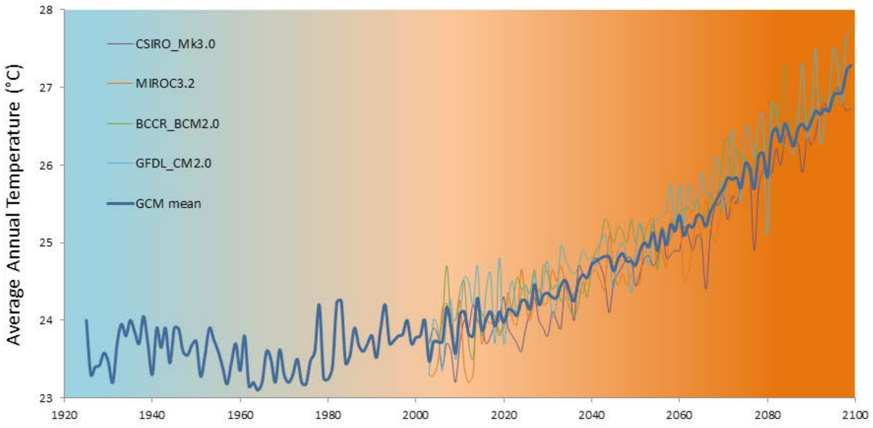
Often, natural resource management implicitly assumes that climatic conditions of the past century will continue through this century. Yet, this assumption is widely and increasingly recognized to be very unlikely given the projected changes in climate. Temperature on average across the Earth has increased by 0.74 degree over the past century (IPCC 2007, right), with 14 of the 16 hottest years occurring in the past two decades. The world is also witnessing increasingly erratic weather, of rainy seasons delayed or un-seasonal showers that destroy crops, a higher frequency of unpredictable extreme precipitation and storms as well as longer droughts, which are likely a consequence of changing climate. Atmospheric CO2 concentrations are building up at an increasing rate, and crossed the 400 ppm level on May 10, 2013. General Circulation Models (GCMs) that have been developed independently by different institutions in different countries all unanimously predict that the warming trend will continue, and that warming is expected to range between 2°C (Greenhouse gas emission scenario B1 that involves significant reductions of emissions along with sequestration) and 4°C (Scenario A2, that is business as usual) by the end of the present century.

A 4°C rise may not seem much given that four degrees is within the same order of seasonal temperature difference in any year, however it is assumed that an increase in temperature will occur over all seasons. The 4°C scenarios are devastating: the inundation of coastal cities; increasing risks for food production potentially leading to higher malnutrition rates; many dry regions becoming dryer, wet regions wetter; unprecedented heat waves in many regions, especially in the tropics; substantially exacerbated water scarcity in many regions; increased frequency of high-intensity tropical cyclones; and irreversible loss of biodiversity, including coral reef systems. And most importantly, a 4°C world is so different from the current one that it comes with high uncertainty and new risks that threaten our ability to anticipate and plan for future adaptation needs.

Even a 1-2 degree shift in temperature appears to be changing weather patterns, including the onset of the rainy season. This shift will lead to increasing uncertainty in onset, distribution and amounts of rainfall, extreme events and the linkages of climate and weather to water, food, livelihoods and biodiversity. Accordingly, a key challenge in planning adaptation strategies will be related to the increasing uncertainty about future climate, and thereby uncertainty in water availability. Adaptive strategies thus require an understanding of current climate in a region and then consider climate predictions under varying scenarios of greenhouse gas emissions.



Global average annual temperature anomaly (difference of annual temperature from the 1961-1990 mean) over 1840-2008. Source: Garnaud Climate Review



Past and future projected temperature for the Wami/Ruvu Basin by four General Circulation Models run at the SRES A2 greenhouse gas emission scenario (current levels of emissions with no decrease). Data source: ClimateWizard.

The overall climate predictions over the 21st century for the Wami/Ruvu Basin are:

Rising temperatures across the seasons, with an increase in very hot days (> 32°C)

Rising evapotranspiration and soil moisture deficits.

Increasing uncertainty in the onset, regularity and amount of rainfall. Occurrence of sizeable rain events in what has been usually considered dry season.

Increasing frequency of extreme events – high rainfall events, floods and long periods of scanty or no rainfall leading to droughts.

Sea level rise, whose negative effects can be compounded by decreases in freshwater river inflows to estuaries.

Source: Government of Tanzania Initial National Communication 2003.

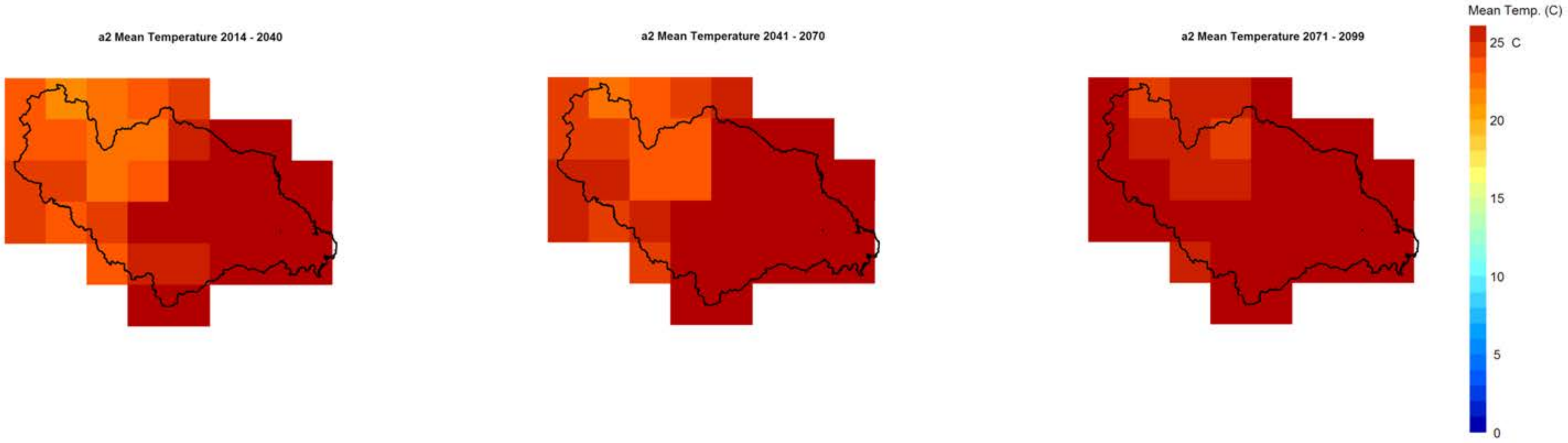
4.1 Temperature

The overall increase in temperature means more hot days and less cool days, which increases cooling energy and water costs for urban centers, industry and power generation.

Increased evaporative water loss impacts water storage in reservoirs as well as surface water sources, while higher temperatures cause more transpiration and water demand for crops.

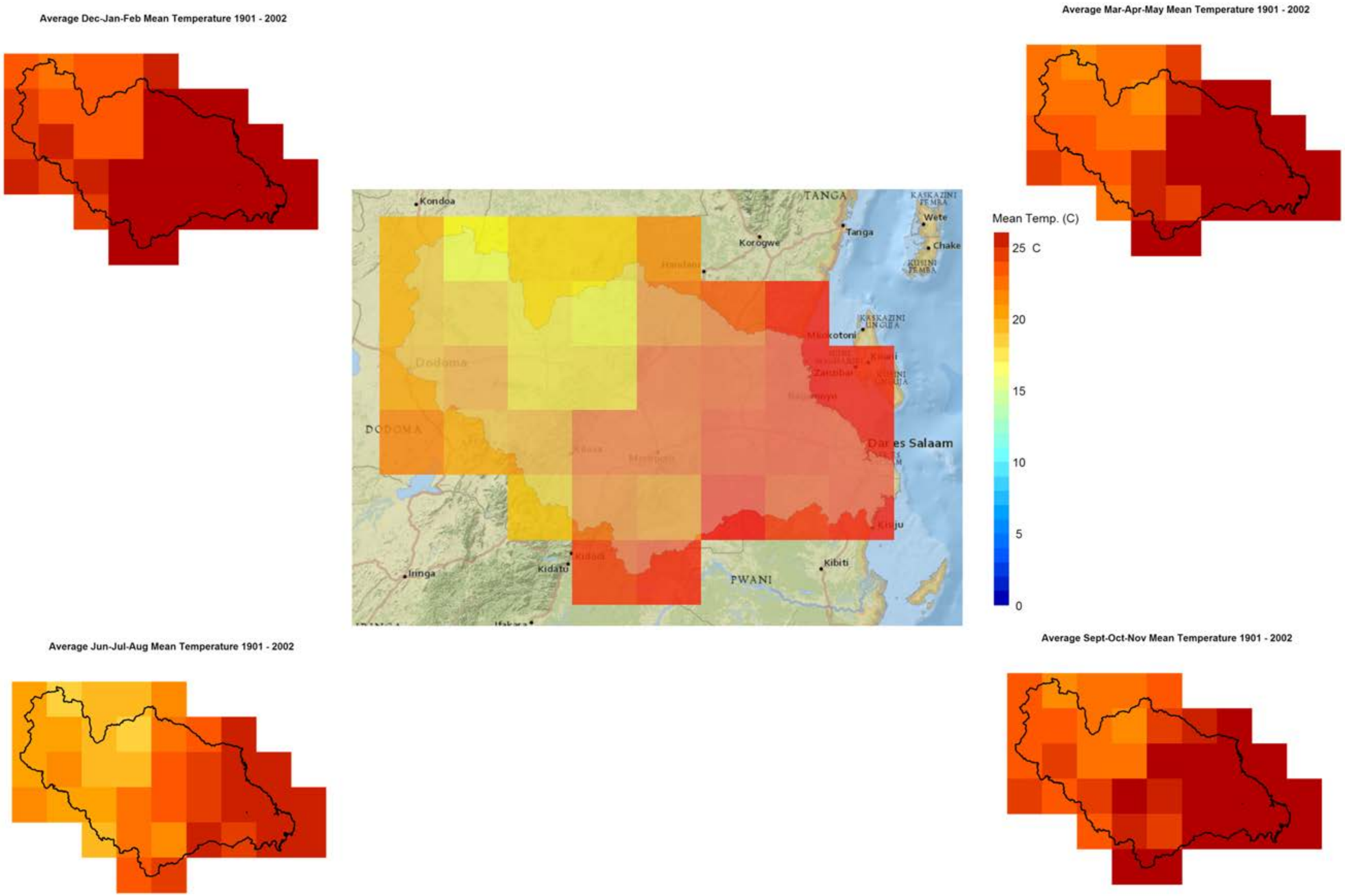
Temperature increases also impact ecosystems by causing species range shifts. An example is the decreasing cloud bases in the Eastern Arcs mountains which lead to shrinking tropical cloud forests along with their animal communities.

There is also the possibility of infectious diseases appearing in new areas, such as malaria moving up mountains. Pest outbreaks are another consequence of temperature shifts.



Annual Temperature Predictions for the Wami Ruvu Basin for 2014-2040 (left), 2041-2070 (centre) and 2071-2099 (right) by an ensemble of 16 General Circulation Models downscaled to a 50 km grid. Source: ClimateWizard

Average annual temperature & seasonal (quarterly) temperature over 1901-2002 for the Wami/Ruvu Basin.


Average Dec-Jan-Feb Mean Temperature 1901 - 2002

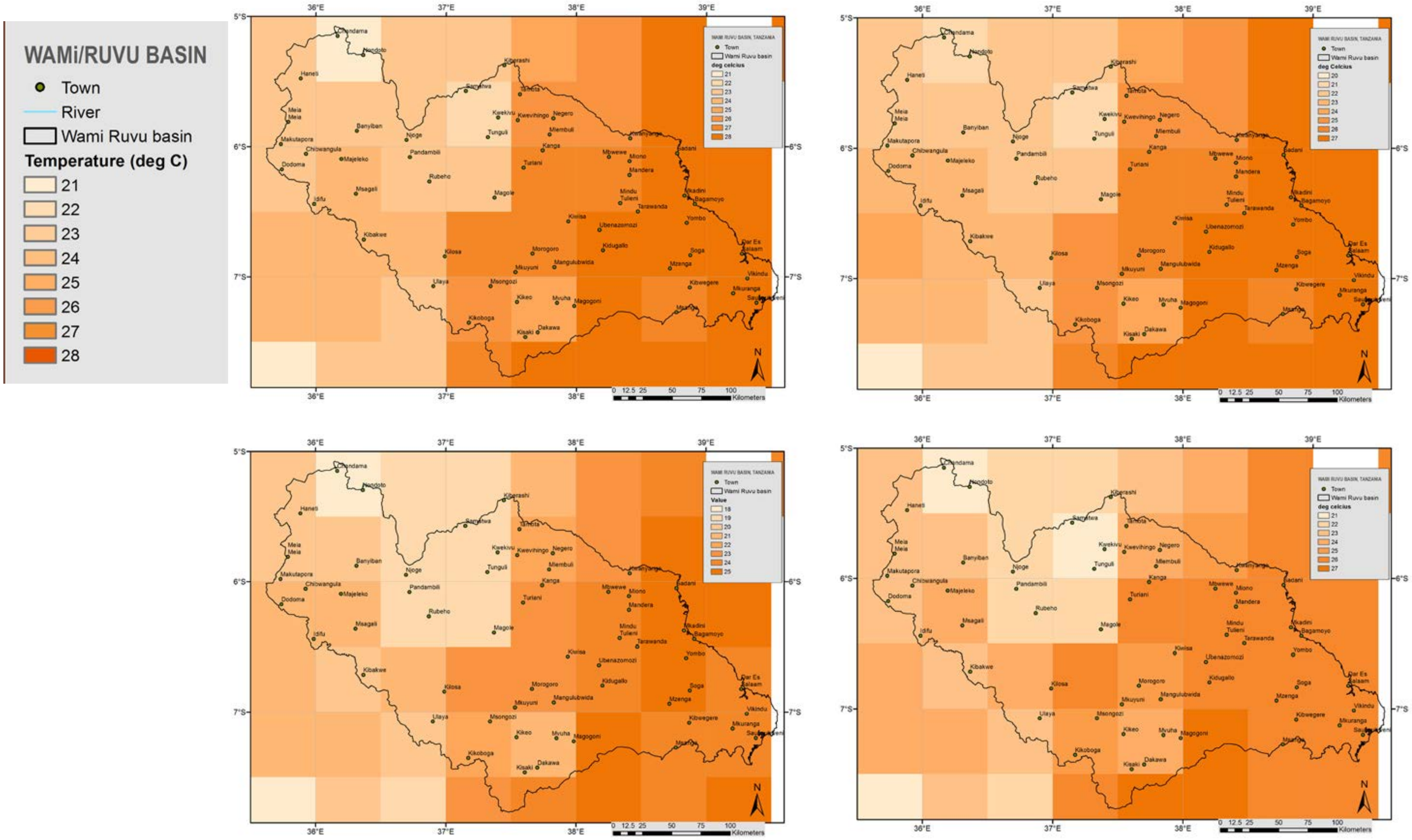
Average Mar-Apr-May Mean Temperature 1901 - 2002

Average Jun-Jul-Aug Mean Temperature 1901 - 2002

Average Sept-Oct-Nov Mean Temperature 1901 - 2002

Upper left: average for December-February; upper right: average for March-May; lower left: average for June-August; lower right: average for September-November mean temperatures for the period 1901-2002. Center: Average annual temperature for the period 1901-2002.
Temperature shown at a 50 km grid. Source: ClimateWizard for climate data layer, ESRI for basemap.

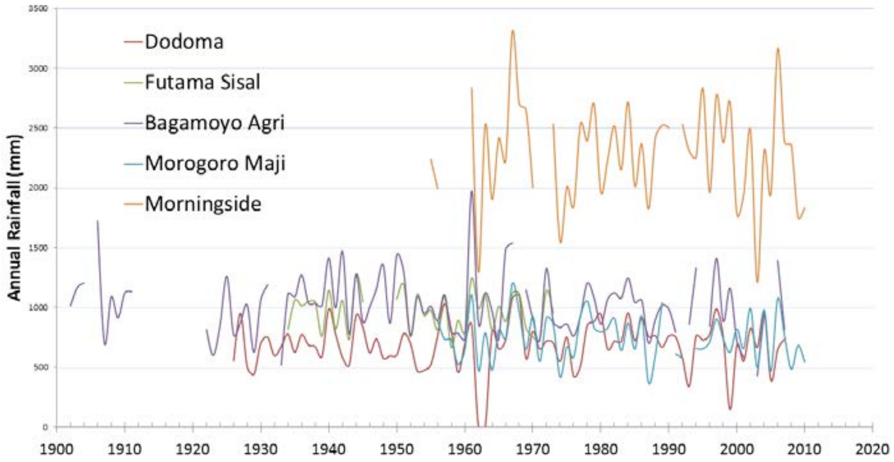
Average annual temperature & seasonal (quarterly) temperature predictions over 2014-2040 for the Wami/Ruvu Basin.



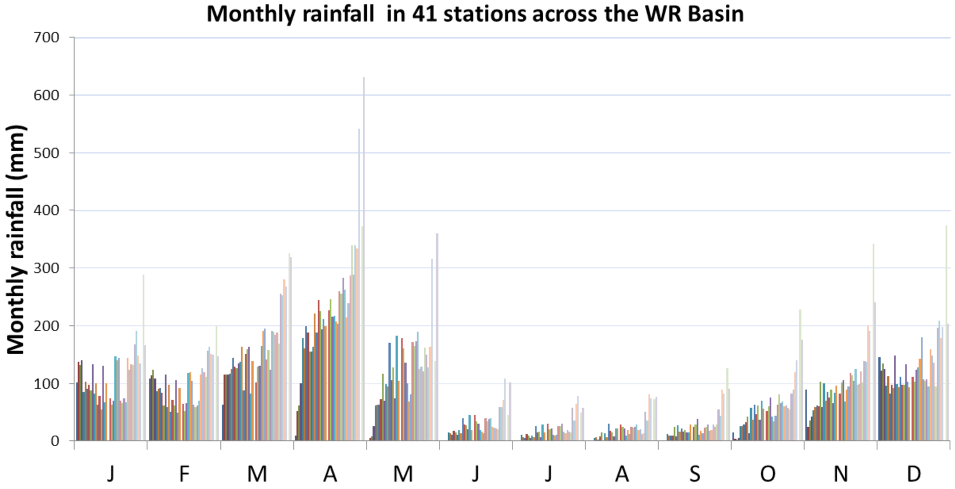
Seasonal temperature projection (2014-2040) for the Wami/Ruvu Basin. Top left (December-February), Top right (March - May), Bottom left (June-August) and Bottom Right (September-November). Prediction by an ensemble of 16 General Circulation Models run at the IPCC SRES A2 (high emissions scenario) and downscaled to a 50 km grid. Source Climatewizard.

4.2 Precipitation

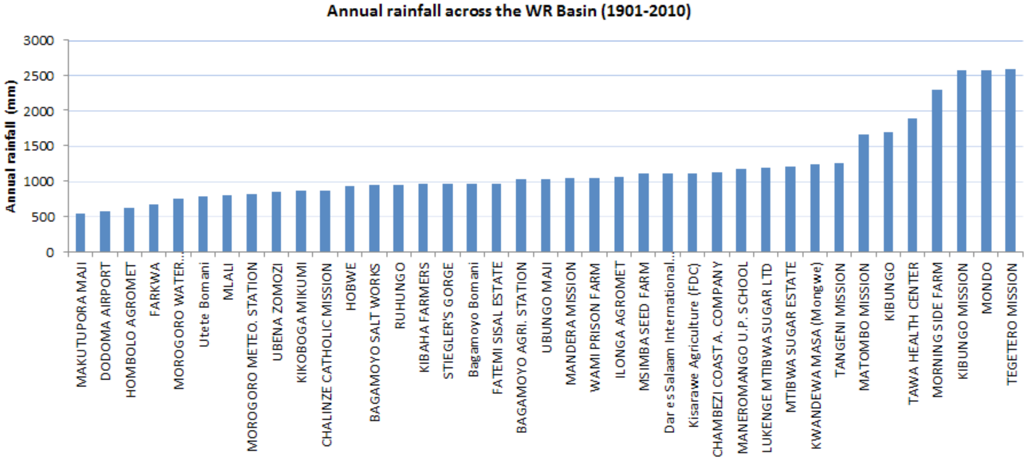
There is a long record of rainfall measurements in the Wami Ruvu basin with some stations beginning in 1901. The long-term data collection at some stations allows for observation of inter-decadal cycles of high and low rainfall (Matayo et al 2000, Valimba 2004, Kijazi & Reason 2005). Also evident is the consistently higher rainfall at Morningside (in the Uluguru Mountains in the Eastern Arc Mountain chain) that receives the highest rainfall in the Basin.



Recorded rainfall at 5 stations in the Wami/Ruvu Basin. Data Source: WRBWO



Monthly rainfall (averaged over 1950-2010 with data gaps) for different stations. The largest rainfall occurs in March-May (masika) with secondary rains in November-February (vuli). Data Source WRBWO

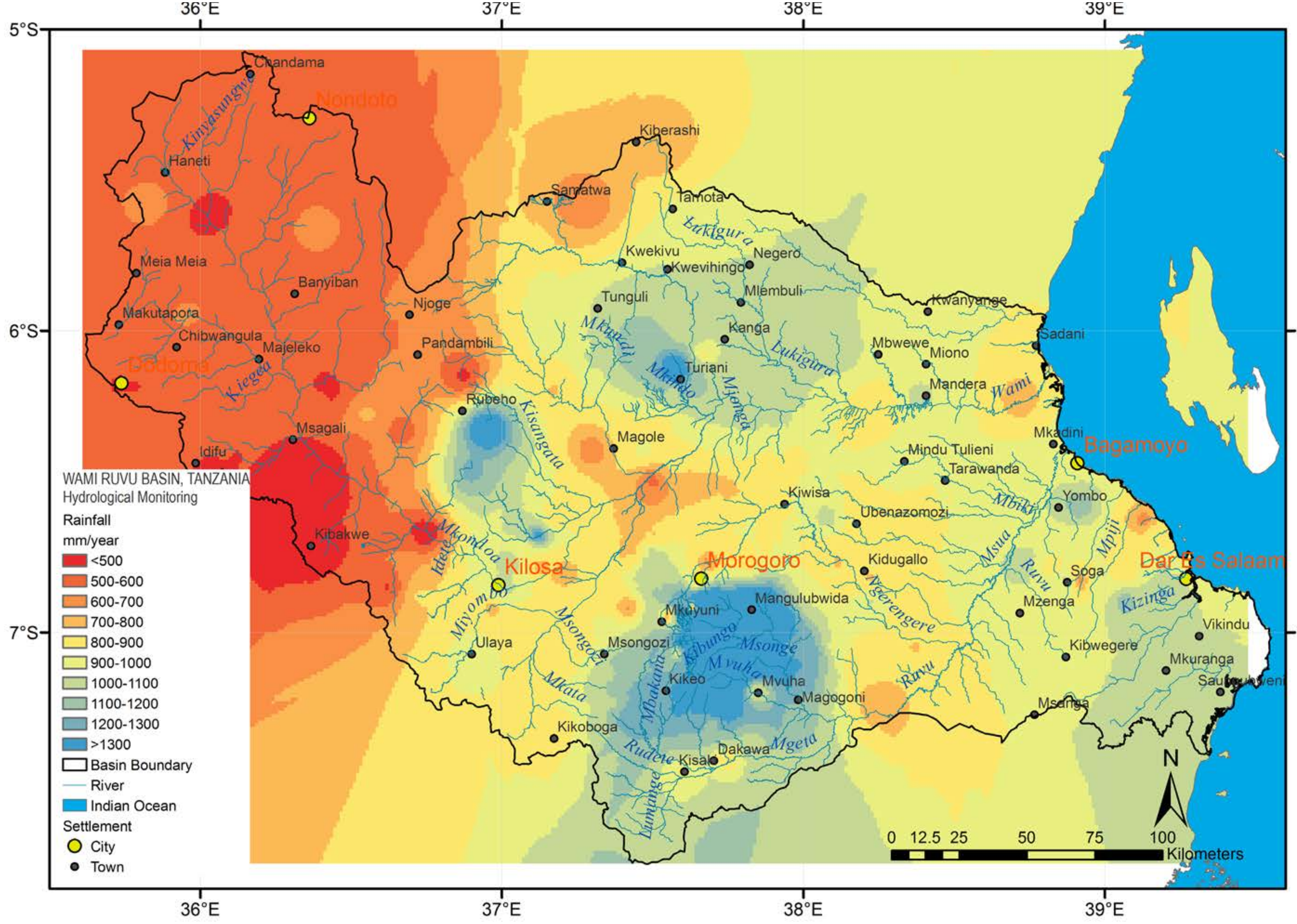


Annual rainfall across the Wami Ruvu Basin, averaged over 1901-2010. Data Source WRBWO

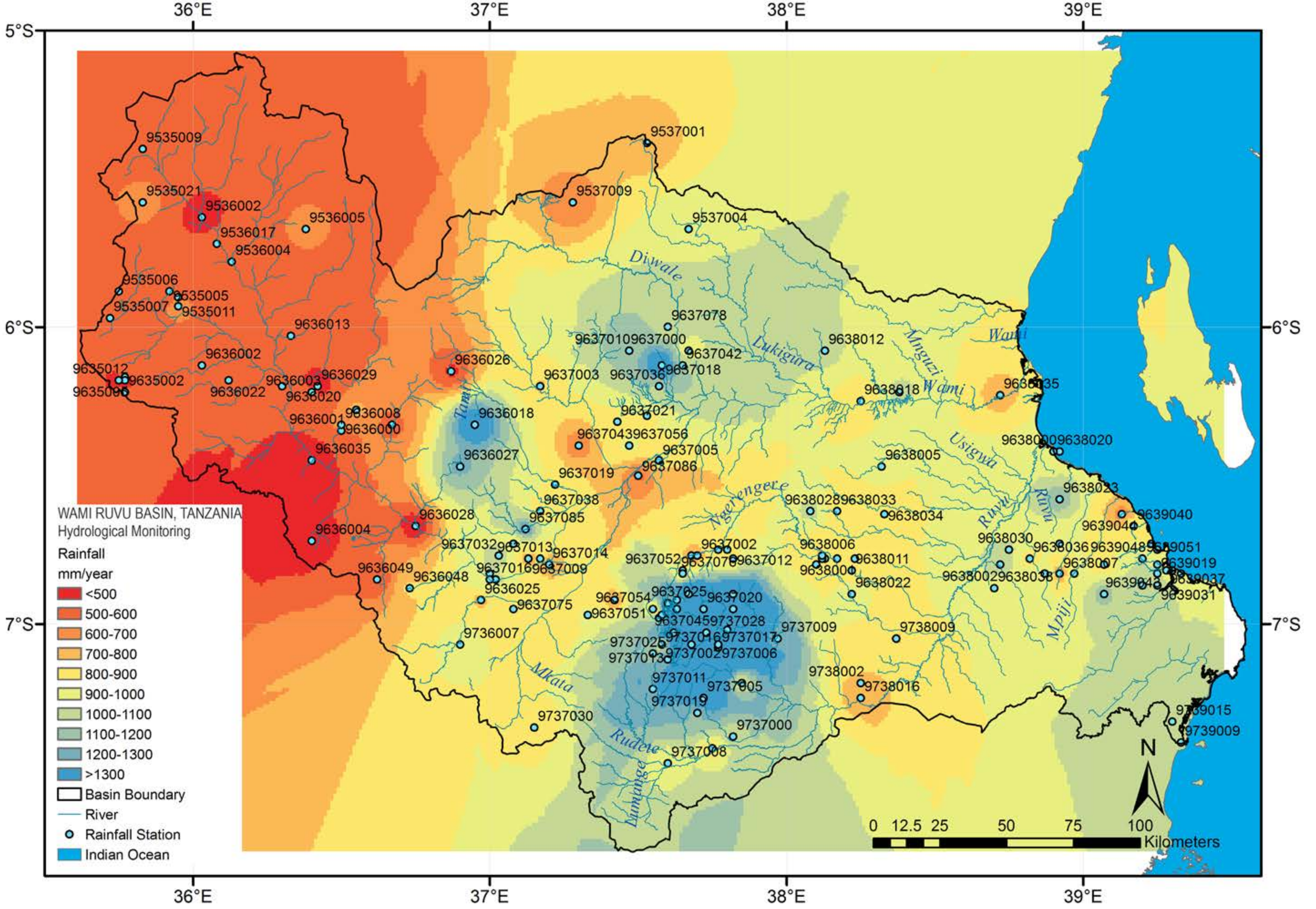
The topography of the basin ranges from flat low-lying land along the coast to the interior plateau (elevation 500-1000 m) to the Eastern Arc Mountains that rise up to 2630 m above sea level in the Uluguru Mountains and up to 2300 m in the Nguru Mountains (Yanda and Munishi, 2007, Gomani et al 2010). Moisture-laden winds blowing westward from the Indian Ocean lose much of their moisture over the Eastern Arc Mountains when forced to rise and undergo adiabatic cooling. The western part of the basin lies in the rain shadow and is thereby semi-arid. The annual rainfall is around 550-750 mm in the western semi-arid highlands near Dodoma, 900-1000 mm in the central areas near Dakawa and in the estuarine and coastal areas.

Most of the rain in the basin falls between March and May (masika rains) with a shorter rainy season in October-December (vuli).

Map_4_1: Isohyets showing annual rainfall averaged over 1950-2010.

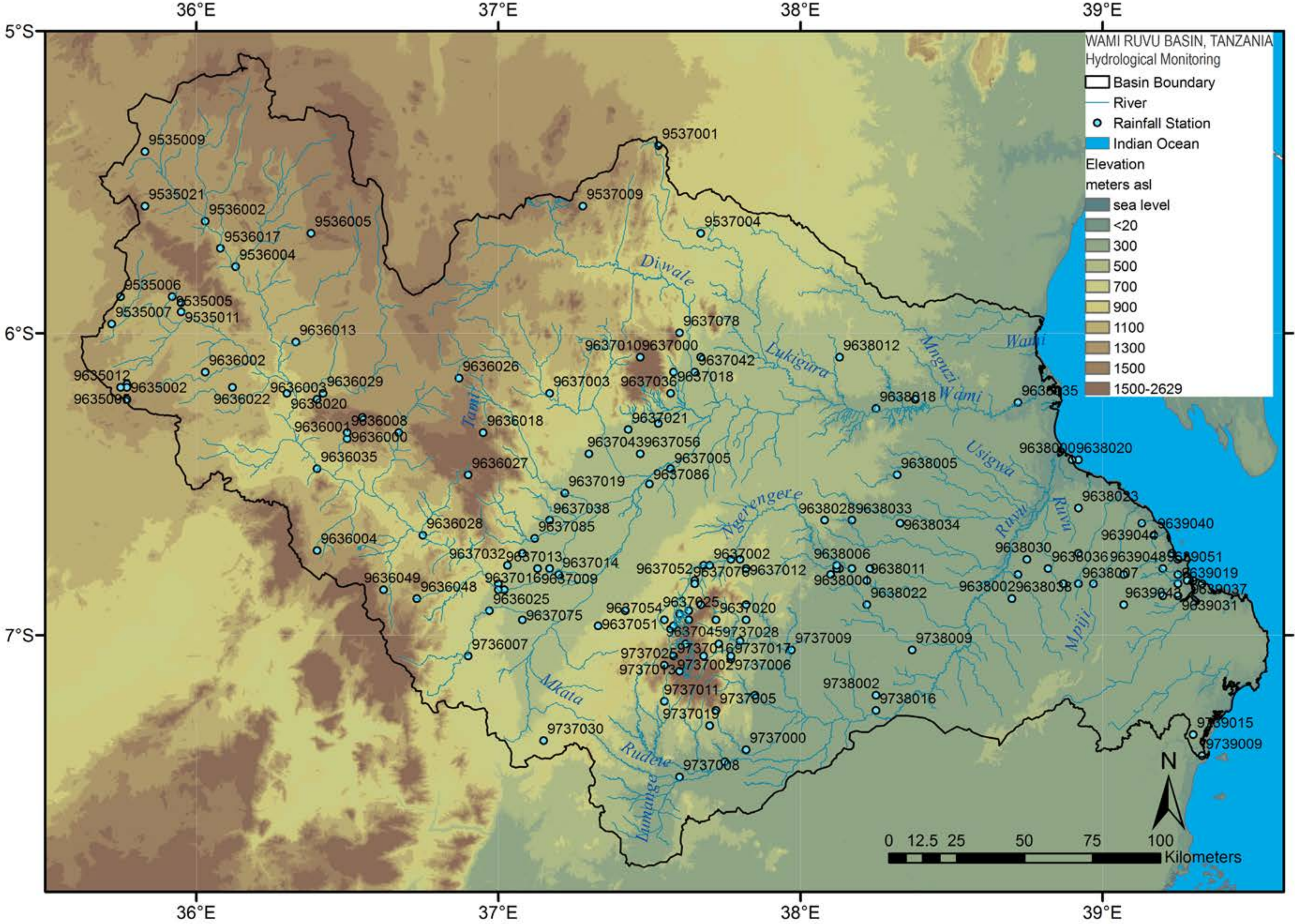


Map_4_2: Rainfall stations and annual average rainfall isohyets averaged over 1950-2010.



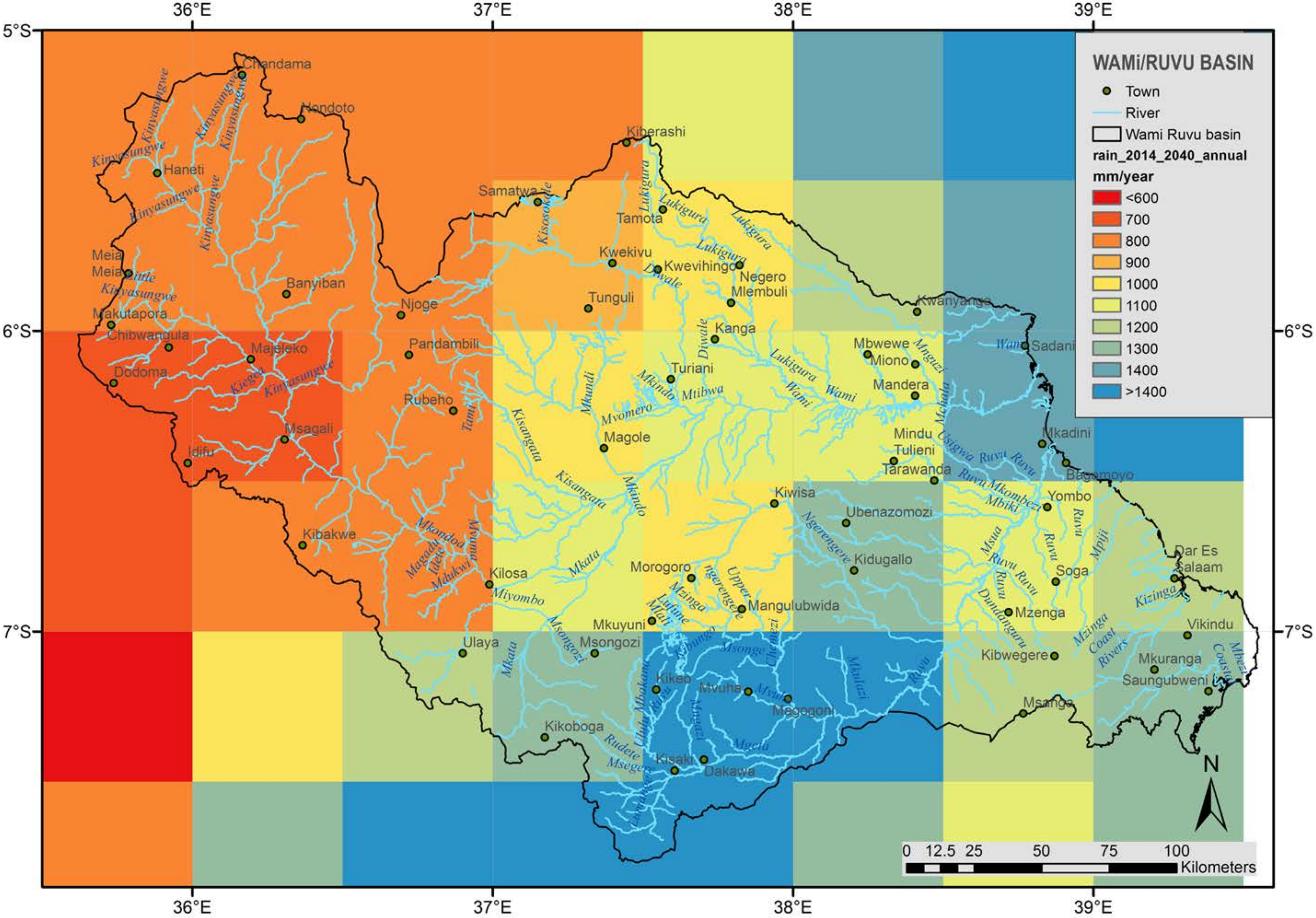
Data Source WRBWO

Map_4_3: Rainfall stations and elevation



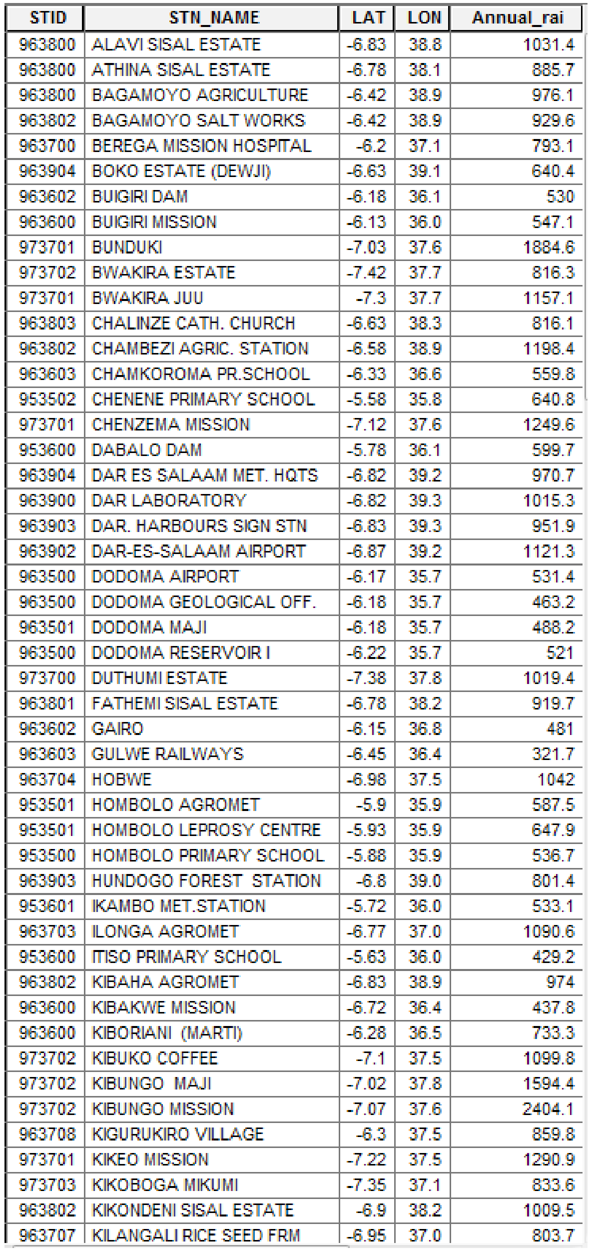
Data Source WRBWO and ASTER-DEM 30 m (NASA and JSRO)

Map_4_4: Projected annual precipitation for the 21st century by an ensemble of 16 GCM's downscaled to a 50 km grid.

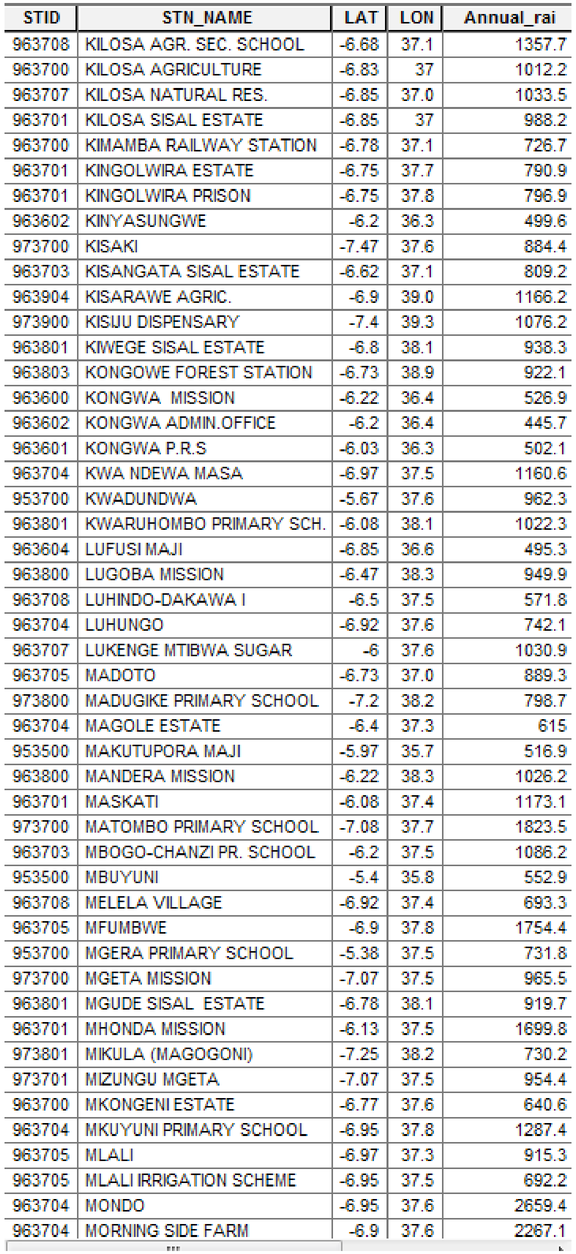


Despite the huge uncertainties in predicting rainfall, the current spatial pattern is preserved (ie: the highest rainfall occurs over the Eastern Arc mountains, intermediate rainfall over the coast and the lowest rainfall in the western arid regions around Dodoma. Source: ClimateWizard

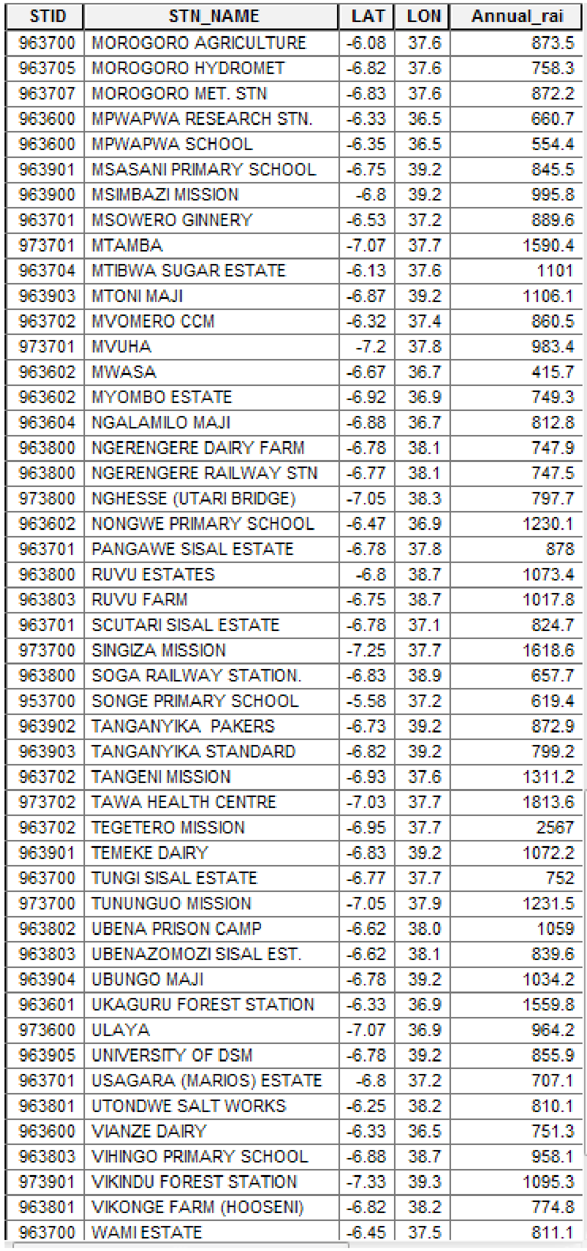
Rainfall station ID, station name with average annual rainfall (1950-2010)



STID	STN_NAME	LAT	LON	Annual_rai
963800	ALAVI SISAL ESTATE	-6.83	38.8	1031.4
963800	ATHINA SISAL ESTATE	-6.78	38.1	885.7
963800	BAGAMOYO AGRICULTURE	-6.42	38.9	976.1
963802	BAGAMOYO SALT WORKS	-6.42	38.9	929.6
963700	BEREGA MISSION HOSPITAL	-6.2	37.1	793.1
963904	BOKO ESTATE (DEWJI)	-6.63	39.1	640.4
963602	BUIGIRI DAM	-6.18	36.1	530
963600	BUIGIRI MISSION	-6.13	36.0	547.1
973701	BUNDUKI	-7.03	37.6	1884.6
973702	BWAKIRA ESTATE	-7.42	37.7	816.3
973701	BWAKIRA JUU	-7.3	37.7	1157.1
963803	CHALINZE CATH. CHURCH	-6.63	38.3	816.1
963802	CHAMBEZI AGRIC. STATION	-6.58	38.9	1198.4
963603	CHAMKOROMA PR.SCHOOL	-6.33	36.6	559.8
953502	CHENENE PRIMARY SCHOOL	-5.58	35.8	640.8
973701	CHENZEMA MISSION	-7.12	37.6	1249.6
953600	DABALO DAM	-5.78	36.1	599.7
963904	DAR ES SALAAM MET. HQTS	-6.82	39.2	970.7
963900	DAR LABORATORY	-6.82	39.3	1015.3
963903	DAR. HARBOURS SIGN STN	-6.83	39.3	951.9
963902	DAR-ES-SALAAM AIRPORT	-6.87	39.2	1121.3
963500	DODOMA AIRPORT	-6.17	35.7	531.4
963500	DODOMA GEOLOGICAL OFF.	-6.18	35.7	463.2
963501	DODOMA MAJI	-6.18	35.7	488.2
963500	DODOMA RESERVOIR I	-6.22	35.7	521
973700	DUTHUMI ESTATE	-7.38	37.8	1019.4
963801	FATHEMI SISAL ESTATE	-6.78	38.2	919.7
963602	GAIRO	-6.15	36.8	481
963603	GULWE RAILWAYS	-6.45	36.4	321.7
963704	HOBWE	-6.98	37.5	1042
953501	HOMBOLO AGROMET	-5.9	35.9	587.5
953501	HOMBOLO LEPROSY CENTRE	-5.93	35.9	647.9
953500	HOMBOLO PRIMARY SCHOOL	-5.88	35.9	536.7
963903	HUNDOGO FOREST STATION	-6.8	39.0	801.4
953601	IKAMBO MET.STATION	-5.72	36.0	533.1
963703	ILONGA AGROMET	-6.77	37.0	1090.6
953600	ITISO PRIMARY SCHOOL	-5.63	36.0	429.2
963802	KIBAHA AGROMET	-6.83	38.9	974
963600	KIBAKWE MISSION	-6.72	36.4	437.8
963600	KIBORIANI (MARTI)	-6.28	36.5	733.3
973702	KIBUKO COFFEE	-7.1	37.5	1099.8
973702	KIBUNGO MAJI	-7.02	37.8	1594.4
973702	KIBUNGO MISSION	-7.07	37.6	2404.1
963708	KIGURUKIRO VILLAGE	-6.3	37.5	859.8
973701	KIKEO MISSION	-7.22	37.5	1290.9
973703	KIKOBOGA MIKUMI	-7.35	37.1	833.6
963802	KIKONDENI SISAL ESTATE	-6.9	38.2	1009.5
963707	KILANGALI RICE SEED FRM	-6.95	37.0	803.7

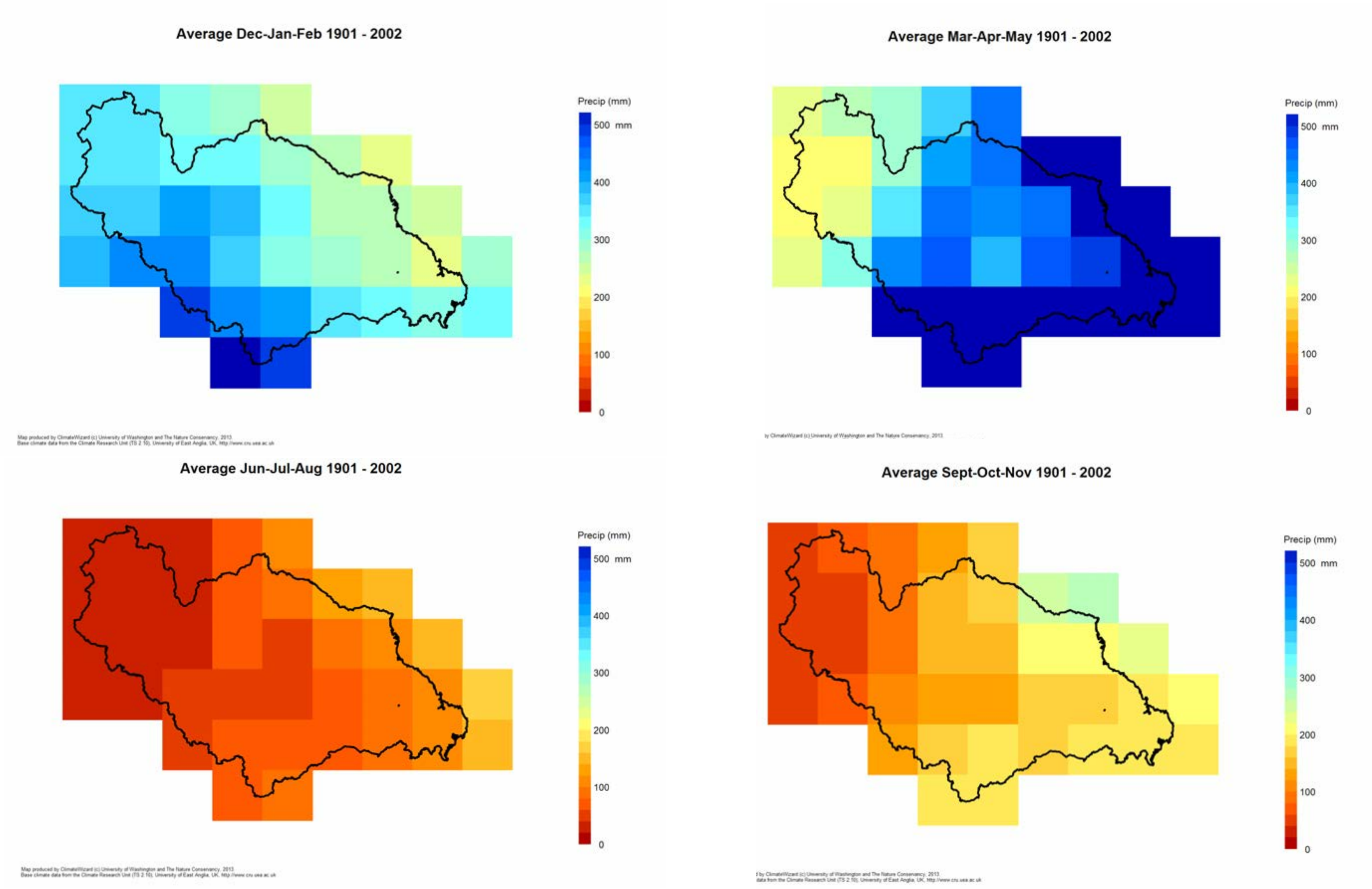


STID	STN_NAME	LAT	LON	Annual_rai
963708	KILOSA AGR. SEC. SCHOOL	-6.68	37.1	1357.7
963700	KILOSA AGRICULTURE	-6.83	37	1012.2
963707	KILOSA NATURAL RES.	-6.85	37.0	1033.5
963701	KILOSA SISAL ESTATE	-6.85	37	988.2
963700	KIMAMBA RAILWAY STATION	-6.78	37.1	726.7
963701	KINGOLWIRA ESTATE	-6.75	37.7	790.9
963701	KINGOLWIRA PRISON	-6.75	37.8	796.9
963602	KINYASUNGWE	-6.2	36.3	499.6
973700	KISAKI	-7.47	37.6	884.4
963703	KISANGATA SISAL ESTATE	-6.62	37.1	809.2
963904	KISARAWE AGRIC.	-6.9	39.0	1166.2
973900	KISIJU DISPENSARY	-7.4	39.3	1076.2
963801	KIWEGE SISAL ESTATE	-6.8	38.1	938.3
963803	KONGOWE FOREST STATION	-6.73	38.9	922.1
963600	KONGWA MISSION	-6.22	36.4	526.9
963602	KONGWA ADMIN.OFFICE	-6.2	36.4	445.7
963601	KONGWA P.R.S	-6.03	36.3	502.1
963704	KWA NDEWA MASA	-6.97	37.5	1160.6
953700	KWADUNDWA	-5.67	37.6	962.3
963801	KWARUHOMBO PRIMARY SCH.	-6.08	38.1	1022.3
963604	LUFUSI MAJI	-6.85	36.6	495.3
963800	LUGOBA MISSION	-6.47	38.3	949.9
963708	LUHINDO-DAKAWA I	-6.5	37.5	571.8
963704	LUHUNGO	-6.92	37.6	742.1
963707	LUKENGE MTIBWA SUGAR	-6	37.6	1030.9
963705	MADOTO	-6.73	37.0	889.3
973800	MADUGIKE PRIMARY SCHOOL	-7.2	38.2	798.7
963704	MAGOLE ESTATE	-6.4	37.3	615
953500	MAKUTUPORA MAJI	-5.97	35.7	516.9
963800	MANDERA MISSION	-6.22	38.3	1026.2
963701	MASKATI	-6.08	37.4	1173.1
973700	MATOMBO PRIMARY SCHOOL	-7.08	37.7	1823.5
963703	MBOGO-CHANZI PR. SCHOOL	-6.2	37.5	1086.2
953500	MBUYUNI	-5.4	35.8	552.9
963708	MELELA VILLAGE	-6.92	37.4	693.3
963705	MFUMBWE	-6.9	37.8	1754.4
953700	MGERA PRIMARY SCHOOL	-5.38	37.5	731.8
973700	MGETA MISSION	-7.07	37.5	965.5
963801	MGUDE SISAL ESTATE	-6.78	38.1	919.7
963701	MHONDA MISSION	-6.13	37.5	1699.8
973801	MIKULA (MAGOGONI)	-7.25	38.2	730.2
973701	MIZUNGU MGETA	-7.07	37.5	954.4
963700	MKONGENI ESTATE	-6.77	37.6	640.6
963704	MKUYUNI PRIMARY SCHOOL	-6.95	37.8	1287.4
963705	MLALI	-6.97	37.3	915.3
963705	MLALI IRRIGATION SCHEME	-6.95	37.5	692.2
963704	MONDO	-6.95	37.6	2659.4
963704	MORNING SIDE FARM	-6.9	37.6	2267.1



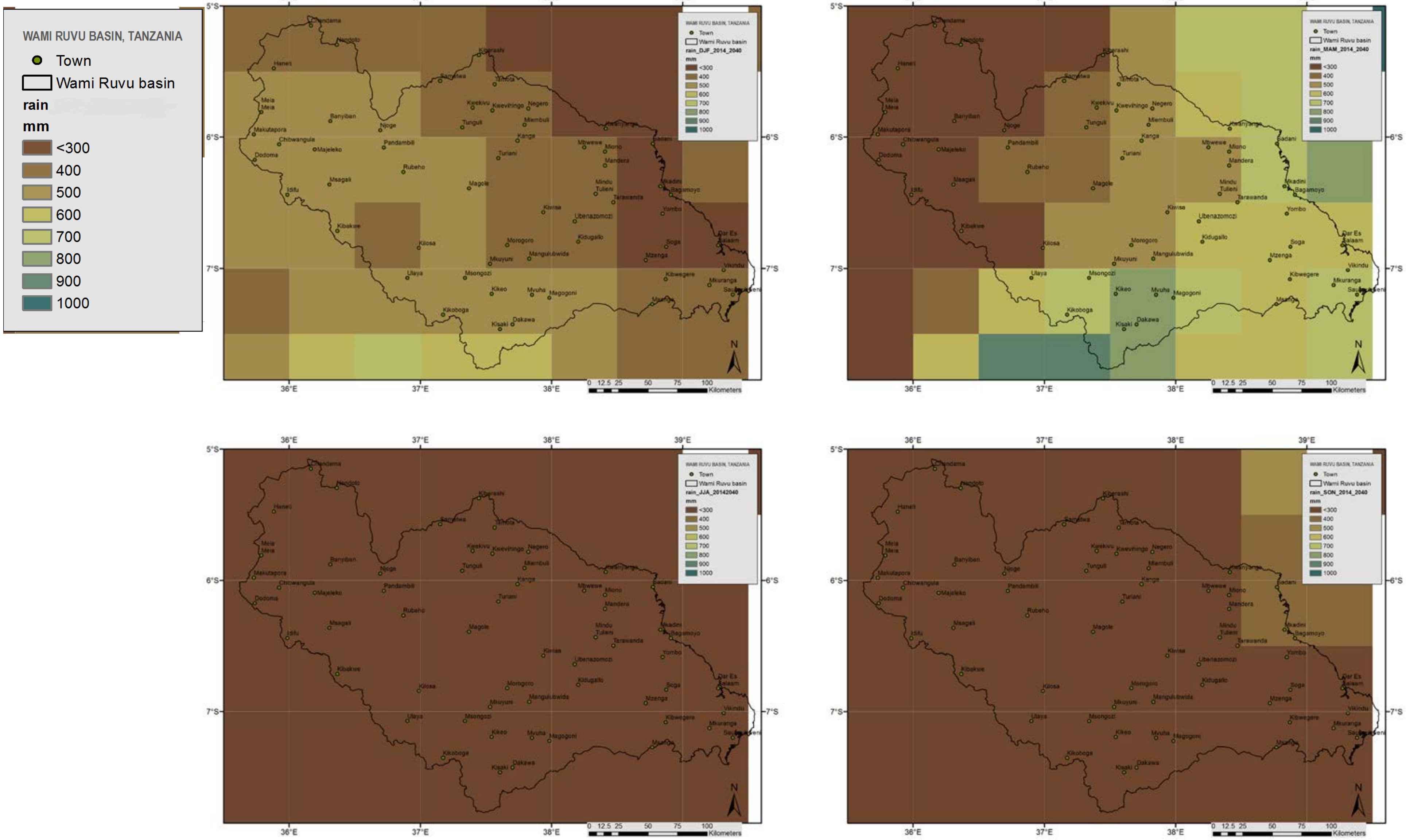
STID	STN_NAME	LAT	LON	Annual_rai
963700	MOROGORO AGRICULTURE	-6.08	37.6	873.5
963705	MOROGORO HYDROMET	-6.82	37.6	758.3
963707	MOROGORO MET. STN	-6.83	37.6	872.2
963600	MPWAPWA RESEARCH STN.	-6.33	36.5	660.7
963600	MPWAPWA SCHOOL	-6.35	36.5	554.4
963901	MSASANI PRIMARY SCHOOL	-6.75	39.2	845.5
963900	MSIMBAZI MISSION	-6.8	39.2	995.8
963701	MSOWERO GINNERY	-6.53	37.2	889.6
973701	MTAMBA	-7.07	37.7	1590.4
963704	MTIBWA SUGAR ESTATE	-6.13	37.6	1101
963903	MTONI MAJI	-6.87	39.2	1106.1
963702	MVOMERO CCM	-6.32	37.4	860.5
973701	MVUHA	-7.2	37.8	983.4
963602	MWASA	-6.67	36.7	415.7
963602	MYOMBO ESTATE	-6.92	36.9	749.3
963604	NGALAMILO MAJI	-6.88	36.7	812.8
963800	NGERENGERE DAIRY FARM	-6.78	38.1	747.9
963800	NGERENGERE RAILWAY STN	-6.77	38.1	747.5
973800	NGHESSE (UTARI BRIDGE)	-7.05	38.3	797.7
963602	NONGWE PRIMARY SCHOOL	-6.47	36.9	1230.1
963701	PANGAWE SISAL ESTATE	-6.78	37.8	878
963800	RUVU ESTATES	-6.8	38.7	1073.4
963803	RUVU FARM	-6.75	38.7	1017.8
963701	SCUTARI SISAL ESTATE	-6.78	37.1	824.7
973700	SINGIZA MISSION	-7.25	37.7	1618.6
963800	SOGA RAILWAY STATION.	-6.83	38.9	657.7
953700	SONGE PRIMARY SCHOOL	-5.58	37.2	619.4
963902	TANGANYIKA PAKERS	-6.73	39.2	872.9
963903	TANGANYIKA STANDARD	-6.82	39.2	799.2
963702	TANGENI MISSION	-6.93	37.6	1311.2
973702	TAWA HEALTH CENTRE	-7.03	37.7	1813.6
963702	TEGETERO MISSION	-6.95	37.7	2567
963901	TEMEKE DAIRY	-6.83	39.2	1072.2
963700	TUNGI SISAL ESTATE	-6.77	37.7	752
973700	TUNUNGUO MISSION	-7.05	37.9	1231.5
963802	UBENA PRISON CAMP	-6.62	38.0	1059
963803	UBENAZOMOZI SISAL EST.	-6.62	38.1	839.6
963904	UBUNGO MAJI	-6.78	39.2	1034.2
963601	UKAGURU FOREST STATION	-6.33	36.9	1559.8
973600	ULAYA	-7.07	36.9	964.2
963905	UNIVERSITY OF DSM	-6.78	39.2	855.9
963701	USAGARA (MARIOS) ESTATE	-6.8	37.2	707.1
963801	UTONDWE SALT WORKS	-6.25	38.2	810.1
963600	VIANZE DAIRY	-6.33	36.5	751.3
963803	VIHINGO PRIMARY SCHOOL	-6.88	38.7	958.1
973901	VIKINDU FOREST STATION	-7.33	39.3	1095.3
963801	VIKONGE FARM (HOOSENI)	-6.82	38.2	774.8
963700	WAMI ESTATE	-6.45	37.5	811.1

Seasonal rainfall averaged over 1901-2002



Seasonal rainfall averaged over 1901-2002 for December-February (upper left), March-May (upper right), June-August (lower left) and September-November (lower right). The main rainy season in the Wami/Ruvu Basin occurs over March-May (masika rains) with a shorter season occurring from November-January (vuli rains). Map produced by ClimateWizard (University of Washington and The Nature Conservancy, 2013). Base climate data from the Climate Research Unit (TS 2.10), University of East Anglia, UK

Seasonal rainfall prediction over 2014-2040



Seasonal rainfall prediction averaged over 2014-2040 for December-February (upper left), March-May (upper right), June-August (lower left) and September-November (lower right) by an ensemble of 16 General Circulation Models run at the A2 scenario and downscaled to a 50 km grid.

4.3 Evapotranspiration (ET)

Evapotranspiration refers to the combined loss of water from the Earth's surface to the atmosphere via the two processes of evaporation and transpiration.

Evaporation involves the loss of water from surface water bodies (lakes, rivers, wetlands, sea) and soil (most of it in the upper soil horizon). High temperatures and sunshine, low atmospheric humidity and breezy conditions increase evaporation. Evaporation is usually measured using evaporation pans.

Transpiration refers to water taken up by plants (mostly through roots) and lost to the atmosphere from leaf surfaces through stomata which open during photosynthesis. Plant species vary widely in the amount of water they lose from their leaves (water use efficiency) , with species from arid and semi-arid areas having evolved varied strategies to lose less water than species in rainier regions, such as waxy leaves in succulents to preserve leaf moisture, or the loss of leaves by tropical deciduous trees during the dry season. Factors affecting transpiration are weather-related (just like evaporation) as well as depend upon vegetation type (water use efficiency, phenology or condition of leaflessness). In addition, transpiration is also limited by water availability for plant uptake, such as soil moisture being less than field capacity during a dry spell, or in the case of mangroves, episodes of high salinity caused by seawater intrusion that limits water uptake by the plants.

A large fraction of water on the Earth's surface is lost to the atmosphere via evapotranspiration (ET). In humid tropical regions, annual ET is more than half of the annual precipitation, and in cases of tropical wetlands, ET almost equals precipitation. In arid areas ET is lower due to lower water availability; however in places like the Okavango delta, where water comes in from surface inflows but very little rainfall, annual ET exceeds annual rainfall.

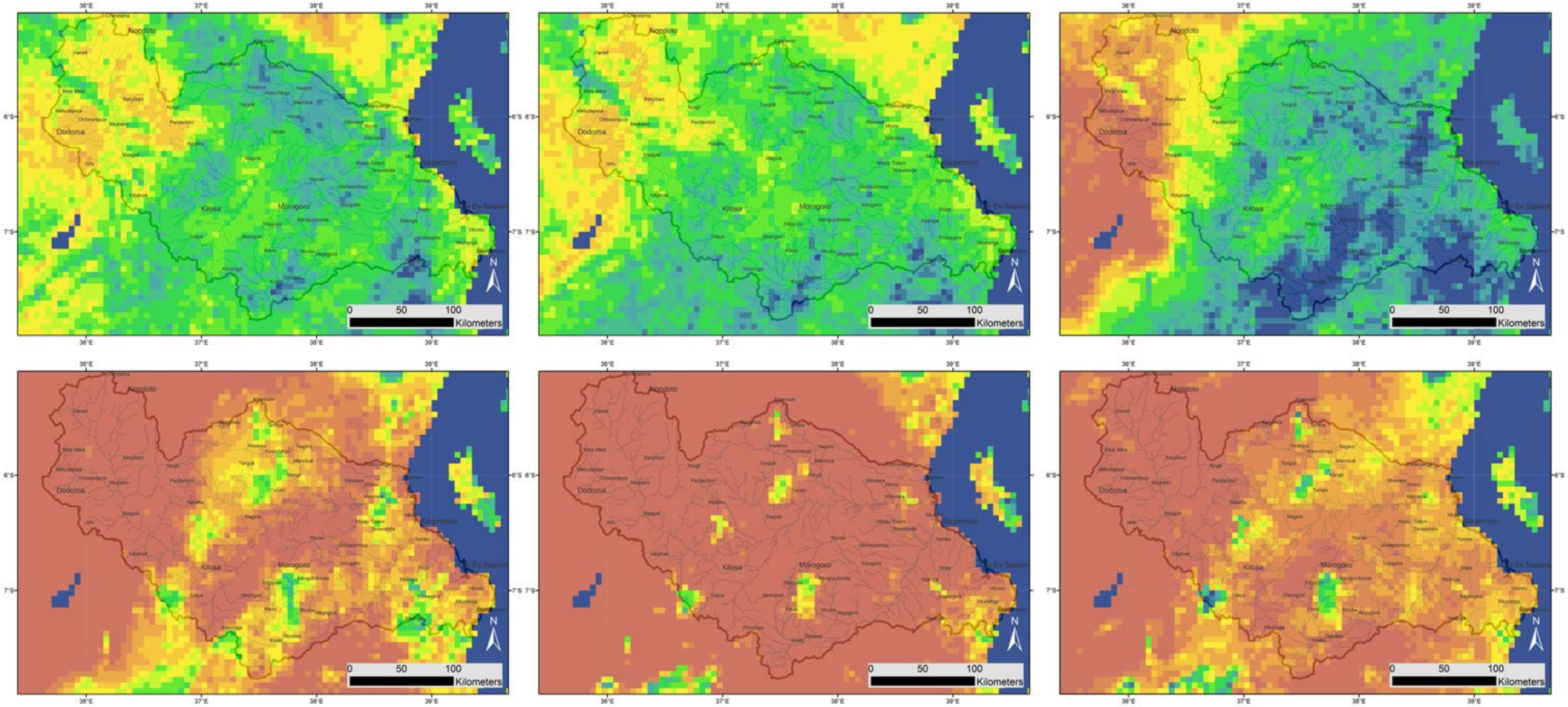
The processes of evaporation and transpiration are primarily driven by solar radiation; relative humidity, windspeed and air temperature also affect ET. ET also depends upon the amount of water available in soil and water bodies as well as the form of vegetation. The maximum possible ET in a region is termed Potential ET (PET) while water limitation results in lower ET, known as Actual ET (AET).

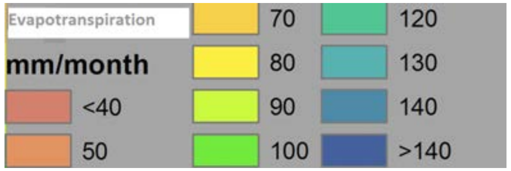
While ET can be estimated reasonably well for irrigated croplands and herbaceous wetlands, it is much harder to accurately estimate ET for woody vegetation such as forests and woody savannas. It cannot be emphasized enough that plant species and forest communities differ greatly in their water uptake and transpiration.

Numerous meteorology-based models exist that have been primarily developed for agriculture. The standardized FAO-Penman-Montieth model is widely used to predict PET based upon net solar radiation, windspeed, relative humidity and air temperature (Saha et al. 2012). The Shuttleworth version adds vegetation height and Leaf Area Index (LAI). Simpler models predict ET from net radiation (Abtew method) or air temperature (Hamon's method) alone, and hence are better suited for regions with scarce meteorological data. Other techniques that estimate ET are tree sap-flow (Granier method), diurnal water table level change (White method) and Eddy Covariance. In addition, remote sensing techniques are being developed to infer soil and canopy moisture from satellite images. MODIS 16 is one such product based on Landsat imagery, offering public-access global ET datasets at a 1 km resolution. The satellite-based inferences have been validated against eddy covariance sites in North America. The following maps have been created from the MODIS 16 global dataset raster product using ArcGIS.

Evapotranspiration leads to the loss of moisture from the Earth's surface into the atmosphere where it forms clouds. In wetland areas, lowland rainforests and tropical montane cloud forests, these clouds re-condense as rain, while in other regions, such as the savanna grassland region between the Ulugurus and Rubeho mountains, the clouds may be carried away by wind currents to other regions.

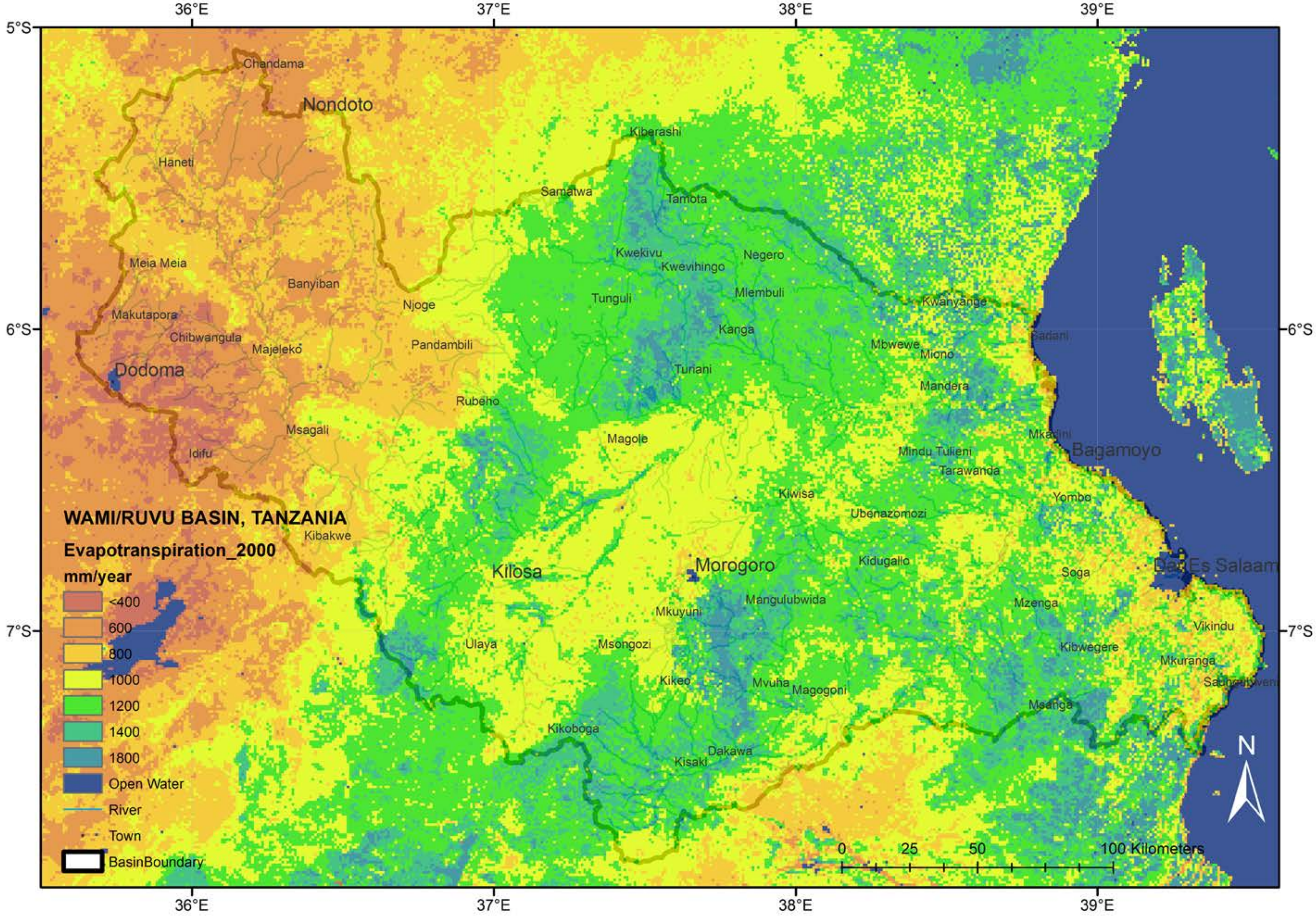
Map_4_5 to Map_4-10: Seasonal Variation in Evapotranspiration (ET) in the Wami/Ruvu Basin





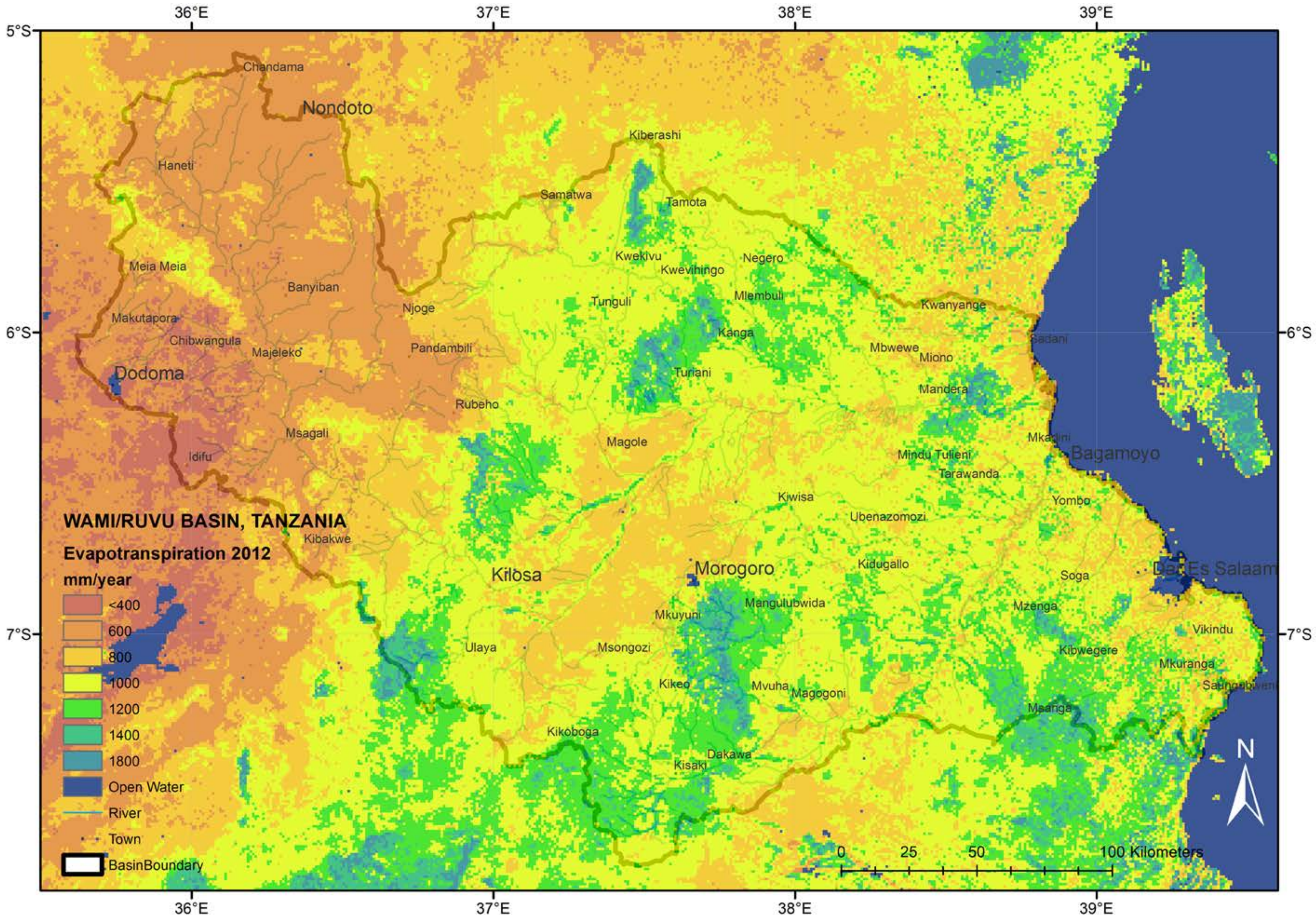
Evapotranspiration in the Wami/Ruvu Basin for January (top left), March (top centre) , May (top right), July (bottom left), September (bottom centre) and November (bottom right). A seasonal pattern in ET is evident, with high values in Jan-May and low values in July-November. The amount of moisture loss through ET depends upon the incident solar energy as well as moisture availability (ranfall). In the dry months, high ET is observed only in the Eastern Arcs mountains and some coastal regions (green and blue values).
Wetter months: higher ET

Map_4_11: Evapotranspiration in the year 2000 at a 1 km resolution



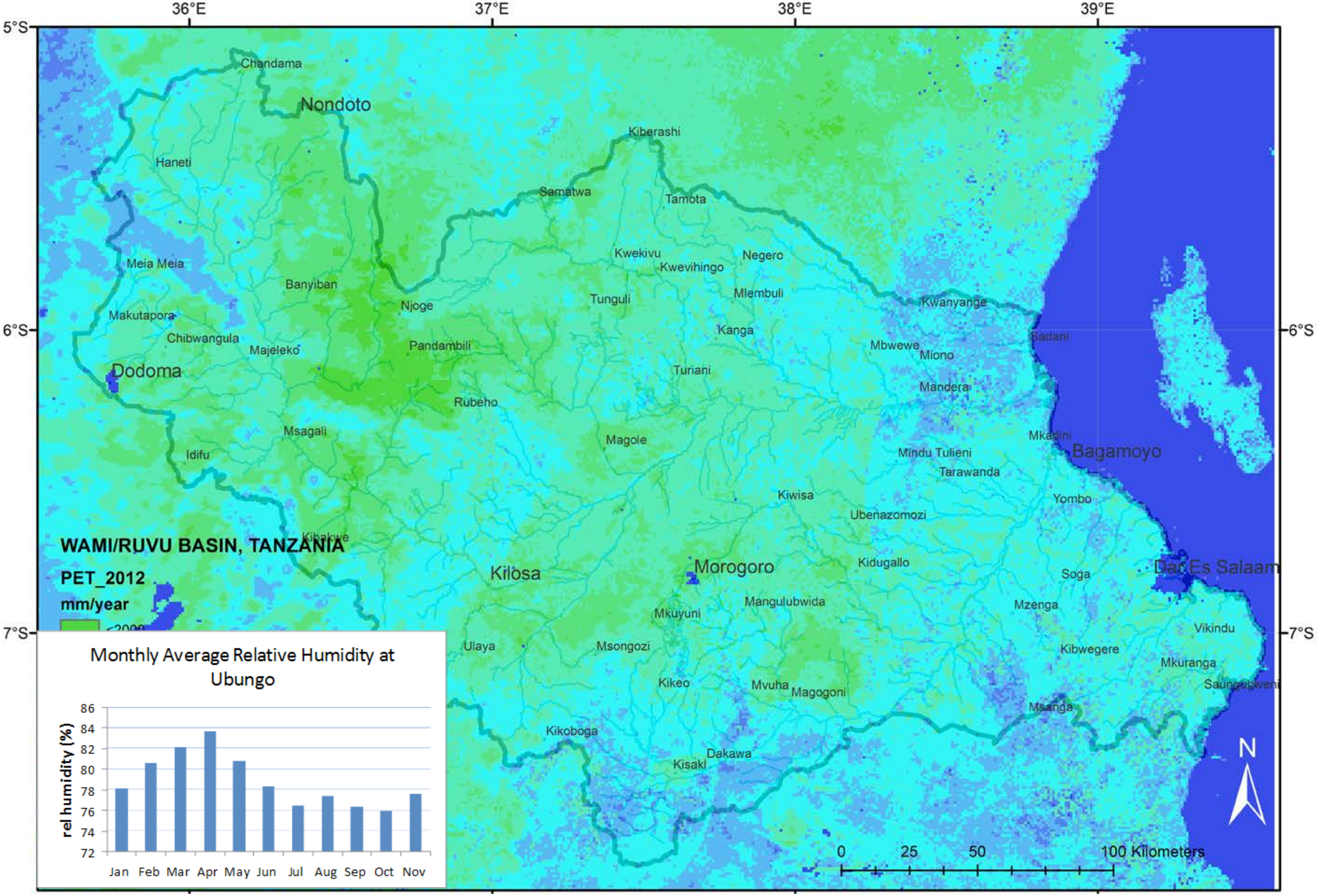
The regions in the Basin with the highest ET are the Eastern Arc mountains, which reflects the high year-round availability of water in these regions. In contrast, the lowlands have lower ET that indicates water limitation during the dry season. Severe water limitation curtails ET in the semi-arid highlands west of the mountains near Dodoma and beyond. Note the open water signal from the Mindu reservoir west of Morogoro. Data source: MODIS 16/ NASA

Map_4_12: Evapotranspiration in the year 2012 at a 1 km resolution



Lower ET in 2012 than in 2000 can be possibly attributed to lower rainfall as well as decreased forest cover.

Map_4_13: Potential Evapotranspiration (PET)

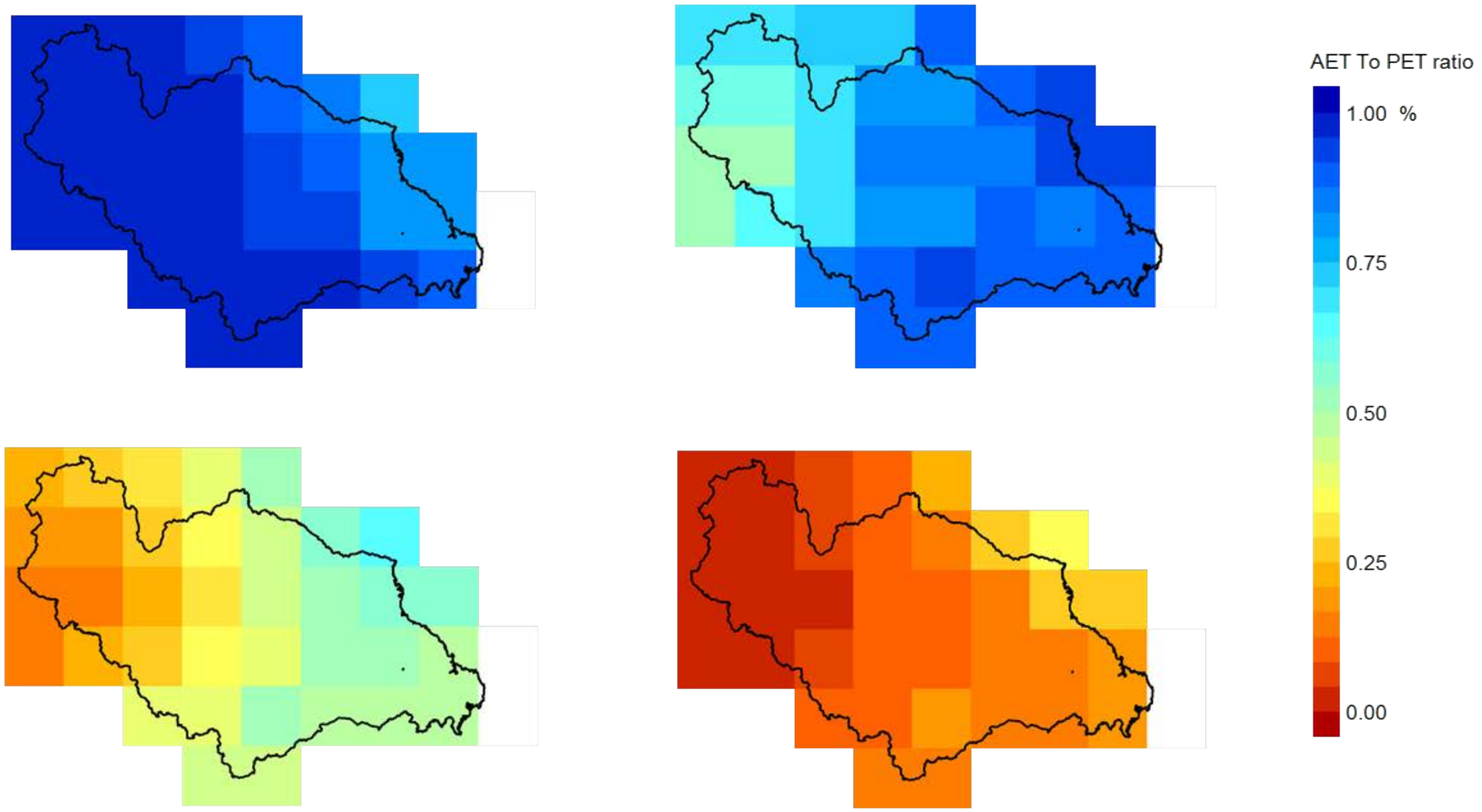


Potential evapotranspiration signifies the amount of evapotranspiration that could occur if there was unlimited water in the soil; hence PET is determined by the amount of net solar radiation present (the difference between incident and reflected solar radiation) which is the main energetic driving force behind ET.

INSET: Monthly Atmospheric Relative Humidity Profile at Ubungo weather station, showing high atmospheric humidity coinciding with the rainy season.

The ratio of Actual ET to Potential ET indicates the extent of water limitation on the landscape. Actual ET takes into account the limited amount of soil moisture, which limits the amount of evapotranspiration flux. In most times of the year, AET is less than PET. AET approaches PET only in the rainy season (as seen in the adjacent maps where the ratio shifts from 1 in the rainy season to < 0.25 in the dry months). In the Wami Ruvu basins, AET/PET is higher in the Eastern Arc mountains in the dry season, reflecting the higher availability of moisture.

Actual evapotranspiration / Potential evapotranspiration (AET/PET) ratio at a 50 km grid scale in the Wami/Ruvu Basin



Actual evapotranspiration / Potential evapotranspiration (AET/PET) ratio at a 50 km grid scale in the Wami/Ruvu Basin averaged over three month periods: January-March (top left), April-June (top right), July-September (bottom left) and October-December (bottom right).

Section 5:

Water resources

5.1 Surface water resources: sub-basins, rivers, wetlands and reservoirs

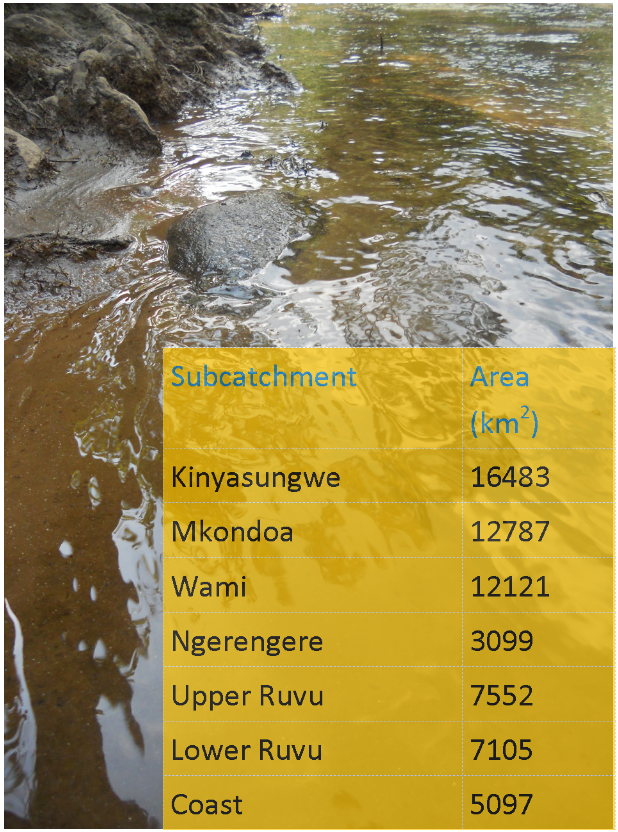
The Wami/Ruvu Basin, as defined administratively, consists of the two main rivers of Wami and Ruvu, and the minor coastal rivers (Mpiji, Sinza, Mlalakuwa, Msimbazi, Mzinga, Kizinga and Mbezi) that all drain into the Indian Ocean, encompassing with a total area of 66,820 km2 (Wami-43,046 km2, Ruvu-18,078 km2 and the Coastal-4,796 km2).

The headwaters of the Wami/Ruvu Basin drain the Ngurus, Ukagurus and the Ulugurus, which are part of the Eastern Arc chain of mountains, a world-renowned hotspot for biological diversity and endemism. The estuary of the Wami River falls within the boundaries of Saadani National Park, the latest addition to the vast network of protected areas in Tanzania, and the country's only park to bridge terrestrial and marine environments. The estuary of the Ruvu river has mangrove forests, seagrass beds, wildlife including hippos, crocodiles and monkeys and supports the coastal livelihoods around the town of Bagamoyo. The central part of the basin covers an agricultural region that includes the Mtibwa Sugar Plantation, Dakawa Rice Fields and Ruvu Paddy Irrigation, three of Tanzania's most significant commercial agricultural operations. Water from the Wami and Ruvu Rivers is used to irrigate these large-scale agricultural operations as well as other smaller farms in the region. The lower parts of the basin have large water supply schemes, namely the two Ruvu River water supply schemes that supply water for domestic and industrial needs for the city of Dar es Salaam and its peri-urban areas, and the Chalinze Water supply scheme on the Wami River which provides water for about 60 villages in Bagamoyo and Morogoro Rural districts.

This section spatially portrays information on the surface water features, hydrogeology and the water users in the basin. Main surface water resources such as rivers and reservoirs are shown against a backdrop of average annual rainfall, thereby providing a spatial perspective on the location of reservoirs vis a vis human settlements and local rainfall quantity. Wetlands store excess surface runoff in the rainy season and recharge shallow groundwater as well as downstream springs and streams. In addition, large amounts of agrochemicals, heavy metals and other contaminants in water are immobilized in wetland soils and taken up by plants; hence earning wetlands the name of kidneys on the landscape. Wetlands are in danger of continued drainage and disappearance. A map showing wetland locations with the rivers is shown.

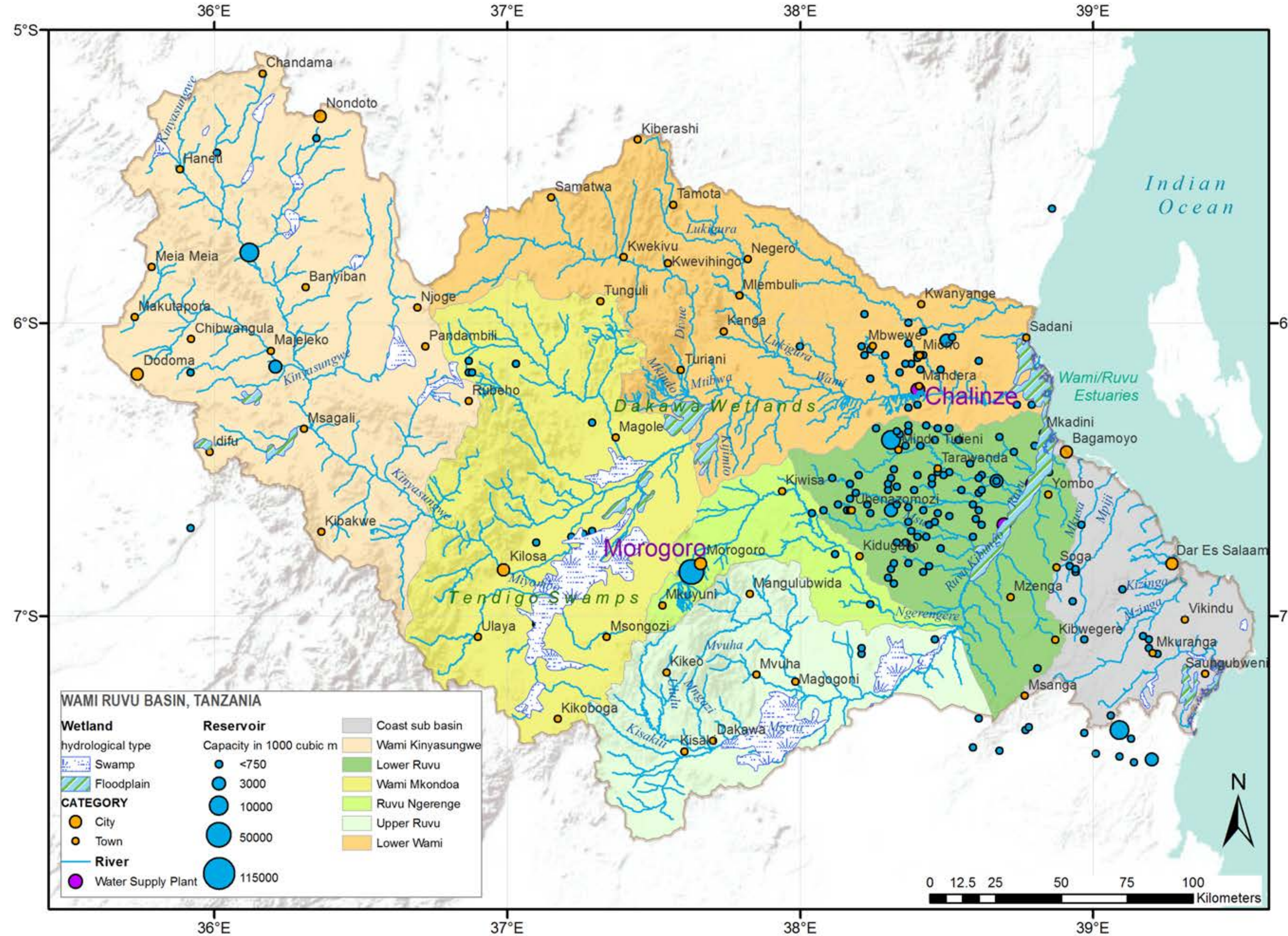
Groundwater is relatively abundant in Tanzania as compared to countries like India and Argentina where extensive use has significantly lowered water tables. In Tanzania, groundwater use is increasing, especially in the western arid areas near Dodoma, as well as in the urban hinterland of Dar es Salaam owing to high population density and the perception that groundwater is of better quality (clear, cool, relatively unpolluted) that water in streams and rivers. In addition, groundwater-irrigated agriculture is on the rise. A monitoring program is essential to keep a track of water table dynamics along with recharge and extraction rates, in order to achieve sustainable groundwater use.

Sustainable water management at the basin scale needs to achieve equitable water sharing for all stakeholders, adequate availability of water for ecosystems to function properly and to plan for increasing demand and climate change. Hence water abstractions from rivers and groundwater require permits from the Basin Water Office. The locations of the permitted water abstraction points in each sector (agriculture, industry and others) are displayed in a series of maps. Being at the basin scale, water users will be densely clustered in certain areas; for greater information, the Digital Atlas has the ability to zoom in on any location within the basin to any extent, and click on each water use permit symbol to gain additional information pertaining to that user, such as the volume of water abstraction authorized, source of water and further information.

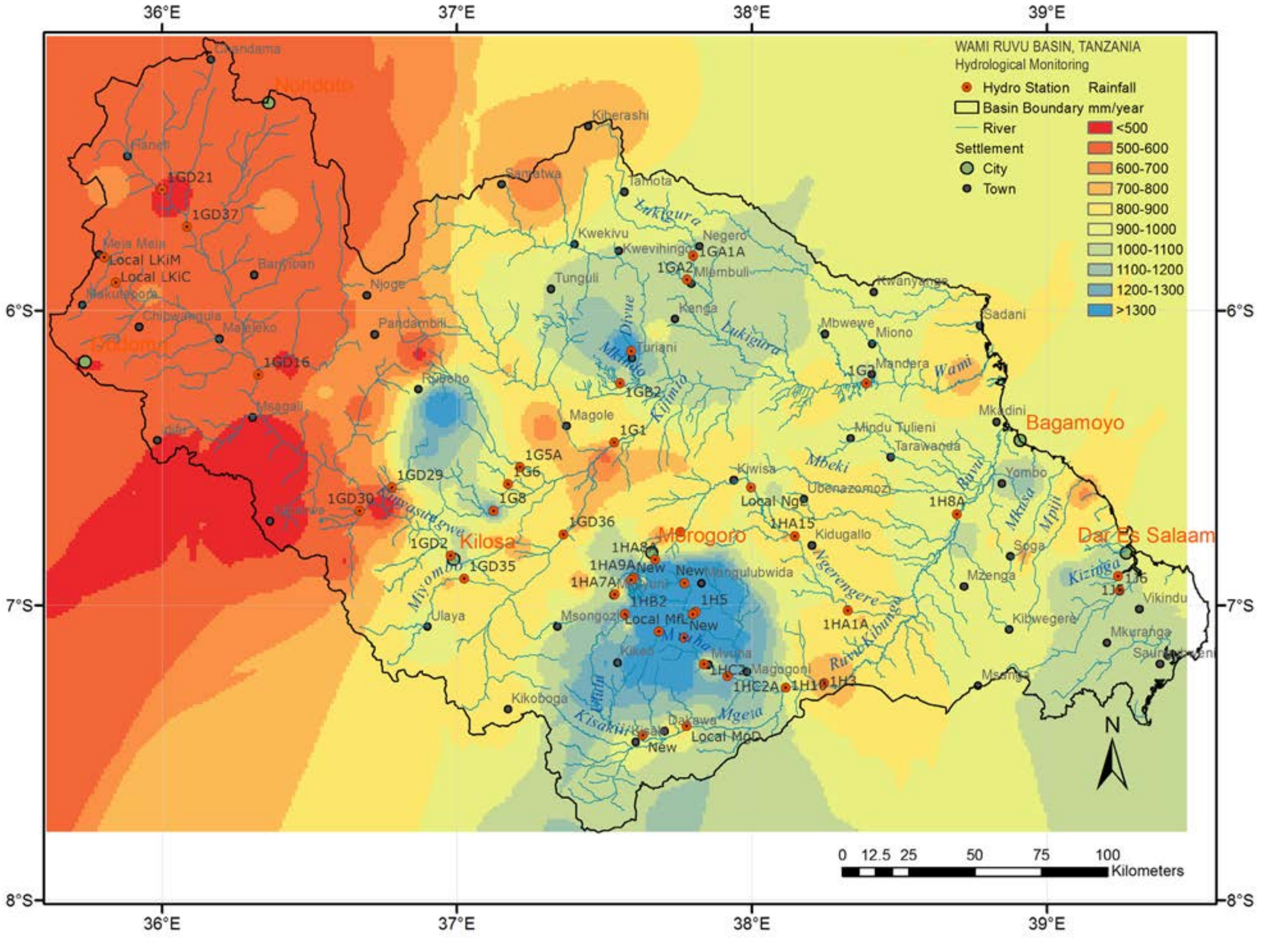


Subcatchment	Area (km^2)
Kinyasungwe	16483
Mkondoa	12787
Wami	12121
Ngerengere	3099
Upper Ruvu	7552
Lower Ruvu	7105
Coast	5097

Map_5_1: Surface water resources of the Wami/Ruvu Basin



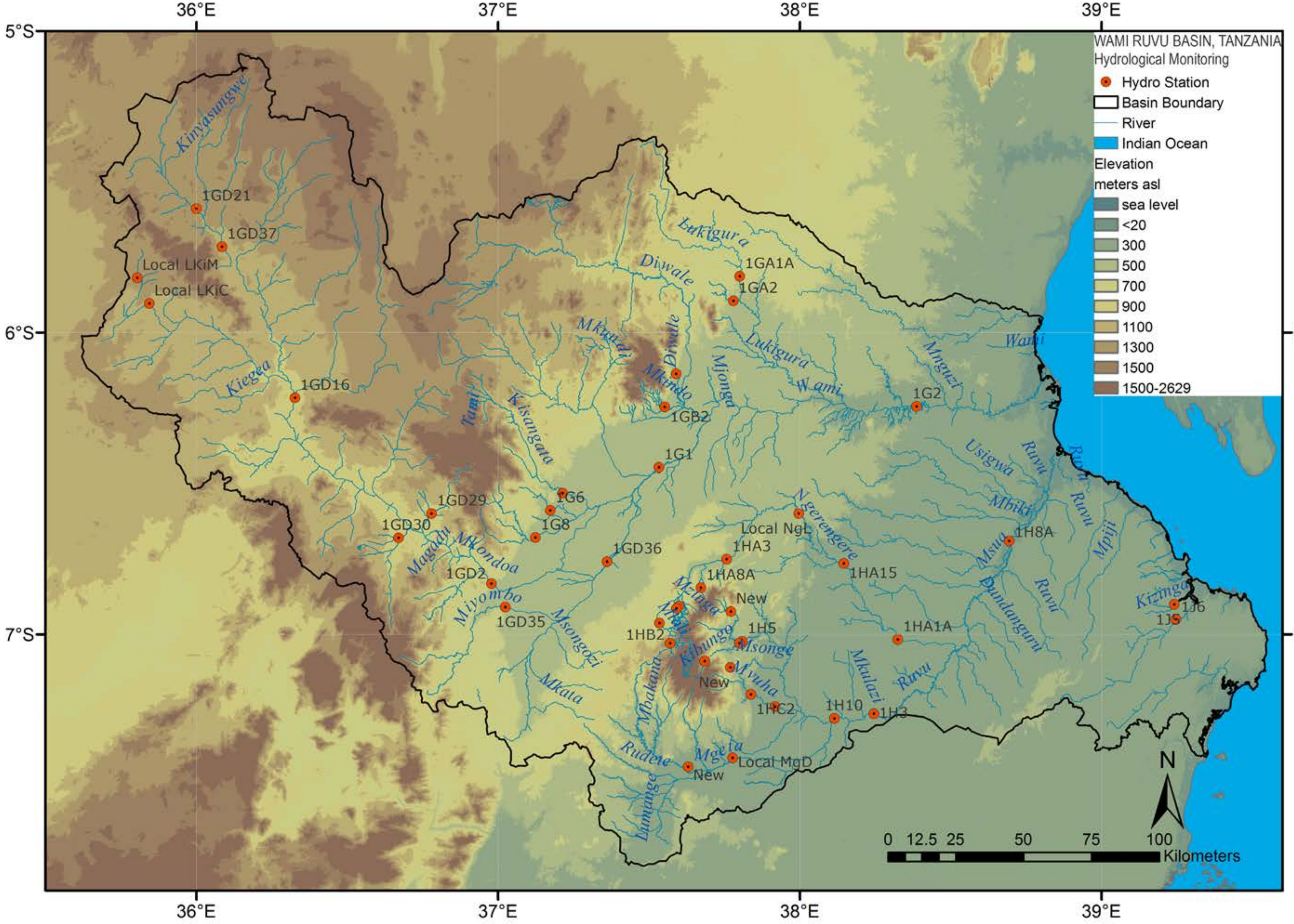
Map_5_2: Hydrological monitoring stations (river level and/or discharge) and average annual rainfall (1950-2010)



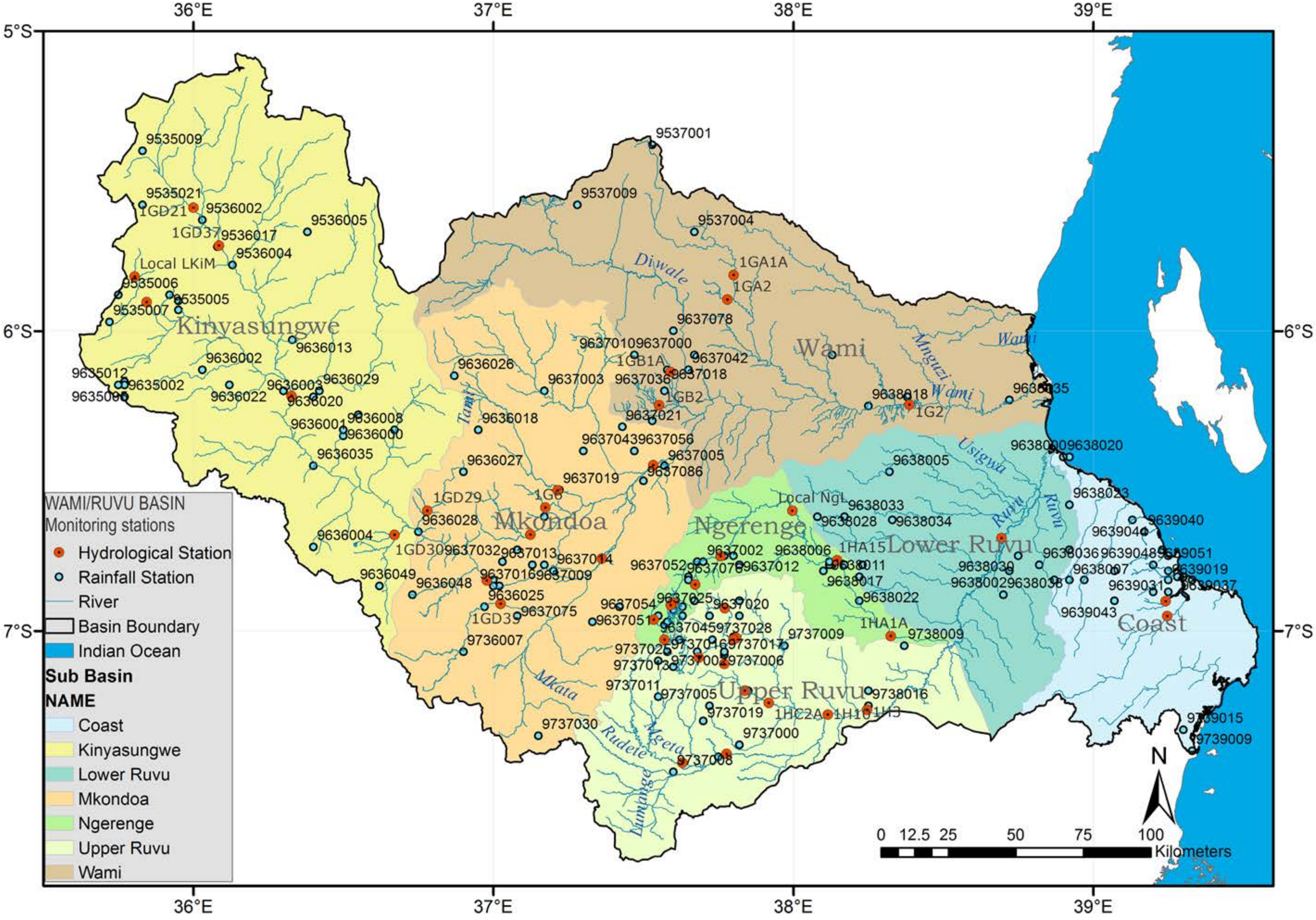
StationCod	StatioName	Basin	RiverName
1G1	Wami at Dakawa	Wami	Wami
1G2	Wami at Mandera	Wami	Wami
1G5A	Tami at Msowero	Wami	Tami
1G6	Kisangata at Mvumi	Wami	Kisangata
1G8	Wami at Rudewa	Wami	Wami
1GA1A	Lukigura at Kimamba Rd. Br.	Wami	Lukigura
1GA2	Mziha at Mziha	Wami	Mziha
1GB1A	Diwale at Ngomeni	Wami	Diwale
1GB2	Mkindo at Mkindo	Wami	Mkindo
1GD2	Mkondoa at Kilosa	Wami	Mkondoa
1GD16	Kinyasungwe at Kongwa/Dodoma	Wami	Kinyasungwe
1GD21	Kinyasungwe at Itiso	Wami	Kinyasungwe
1GD29	Mkondoa at Mbarahwe	Wami	Mkondoa
1GD30	Lumuma at Kilimalulu	Wami	Lumuma
1GD35	Miyombo at Kivungu	Wami	Miyombo
1GD36	Mkata at Mkata	Wami	Mkata
1GD37	Great Kinyasungwe at Ikombo	Wami	Great Kinyasungwe
Local LKiC	Little Kinyasungwe at Chihanga	Wami	Little Kinyasungwe
Local LKiM	Little Kinyasungwe at Mayamaya	Wami	Little Kinyasungwe
1H3	Ruvu at Kidunda	Ruvu	Ruvu
1H5	Ruvu at Kibungo	Ruvu	Ruvu
1H8A	Ruvu at Morogoro Rd. Br.	Ruvu	Ruvu
1H10	Ruvu at Mikula	Ruvu	Ruvu
1HA1A	Ngerengere at Utari Bridge	Ruvu	Ngerengere
1HA3	Ngerengere at Kingolwira	Ruvu	Ngerengere
1HA8A	Morogoro at Morogoro	Ruvu	Morogoro
1HA9A	Ngerengere at Konga	Ruvu	Ngerengere
1HA15	Ngerengere at Mgude	Ruvu	Ngerengere
Local NgL	Ngerengere at Lukwambe	Ruvu	Ngerengere
1HB2	Mgeta at Mgeta	Ruvu	Mgeta
Local MgD	Mgeta at Duthumi	Ruvu	Mgeta
1HC2	Mvuha at Ngagama	Ruvu	Mvuha
1HC2A	Mvuha at Tulo School	Ruvu	Mvuha
Local MfK	Mfizigo at Kibangile	Ruvu	Mfizigo
Local MfL	Mfizigo at Lanzi	Ruvu	Mfizigo
1J5	Kizinga at Mbagala/Buza	Coast	Kizinga
1J6	Mzinga at Majimatitu	Coast	Mzinga
New	Mngazi at Vigolegole	Ruvu	Mngazi
New	Mbezi at Kalundwa(Kinole)	Ruvu	Mbezi
1HA7A	Mlali at Mlali	Ruvu	Mlali
New	Mtombozi at Mtombozi	Ruvu	Mtombozi
New	Lukulunge at Konga	Ruvu	Lukulunge

Hydrological monitoring station codes and names.

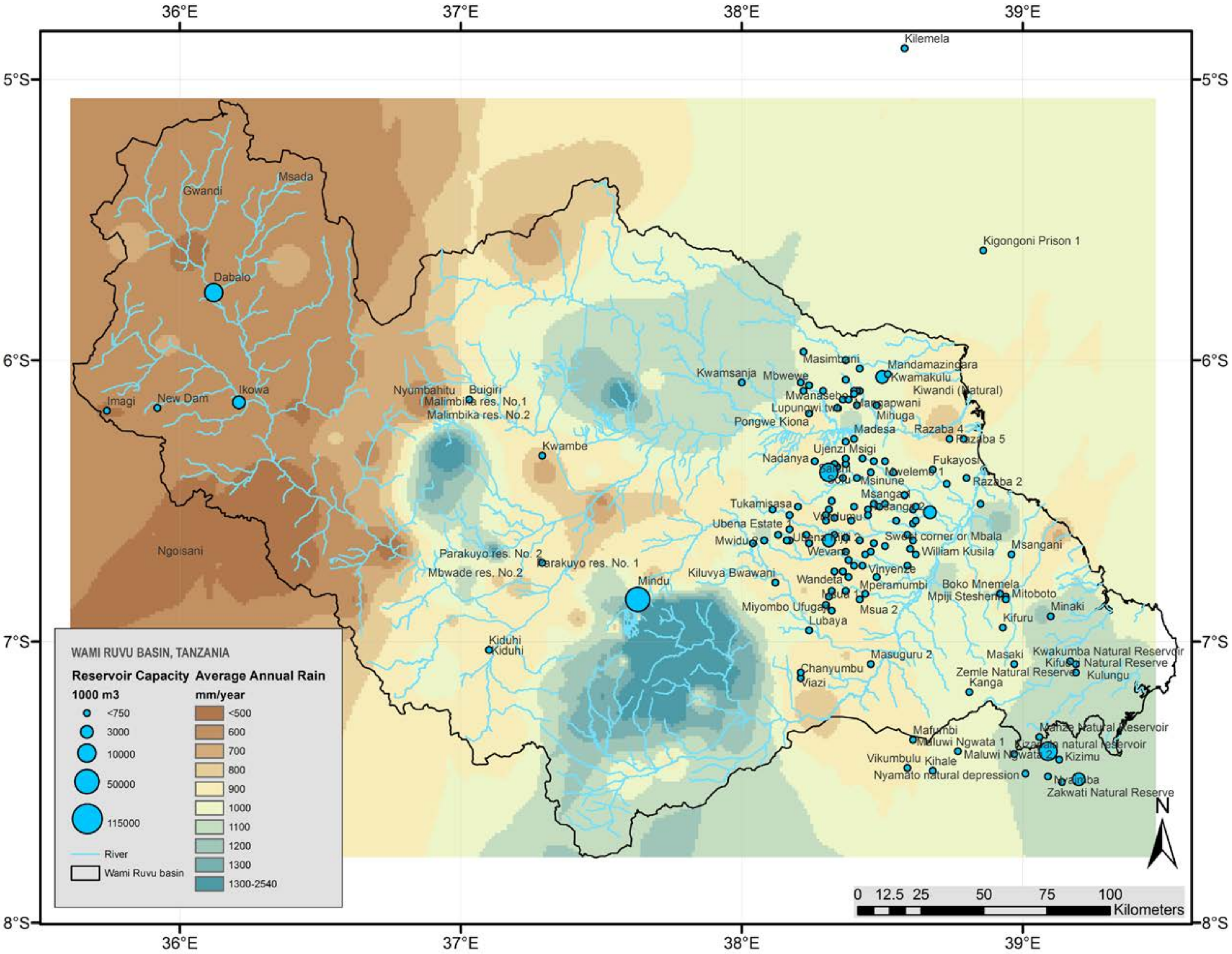
Map_5_3: Hydrological monitoring stations and topographic elevation



Map_5_4: Rainfall and river level/discharge monitoring stations in different subcatchments



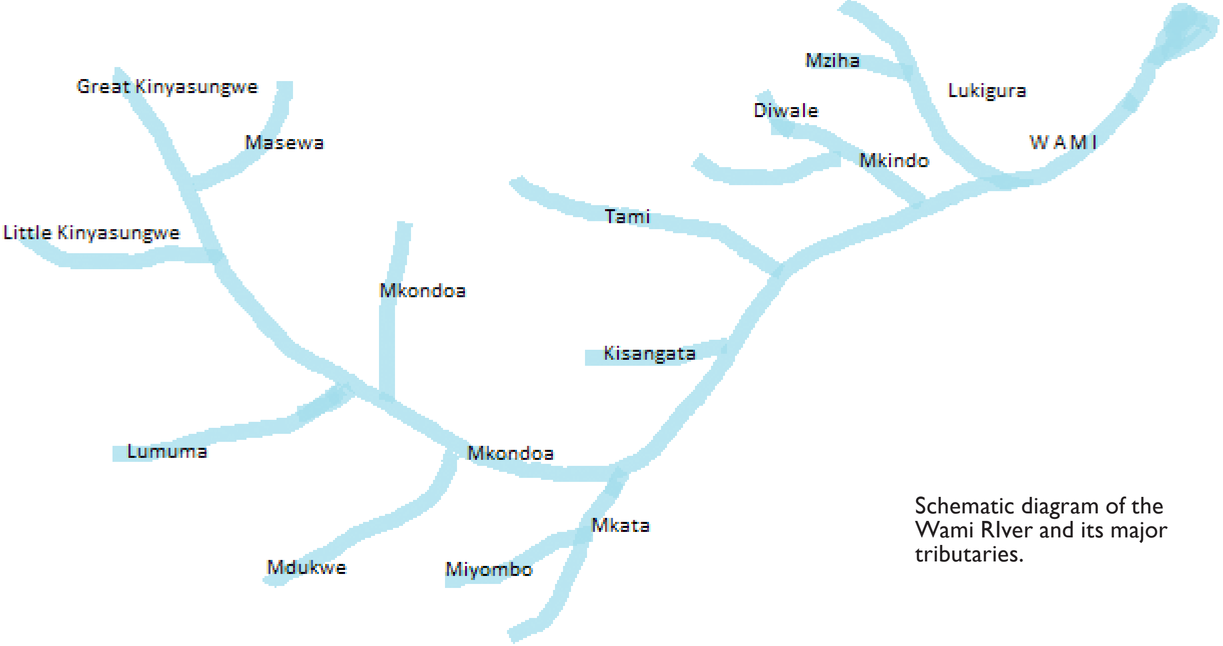
Map_5_5: Surface water reservoirs against a backdrop of average annual rainfall (1950-2010)



Wami River System

The Wami sub-basin river network (IUCN 2010) comprises the main Wami River and its five major tributaries—Lukigura, Diwale, Tami, Mvumi/Kisangata and Mkata. The Mkata tributary is the largest and includes two major sub tributaries, the Miyombo and the large Mkondoa. The Mkondoa River includes the major Kinyasungwe tributary with the Great and Little Kinyasungwe. Located within 5–7°S and 36–39°E, the Wami basin area , approximately 40,000 km2 extends from the upper catchments in the semi-arid Dodoma region through the humid inland swamps of the Morogoro region to discharge into the Indian Ocean at Saadani in Bagamoyo, Coast Region. The river network in the Wami sub-basin drains the arid tracts of Dodoma, the central mountains of Rubeho and Nguu and the northern Nguru Mountains catchments in Dodoma.

The Wami River sub-basin can be divided into six hydrologic zones: Kinyasungwe, Mkondoa, Mkata, Diwale, Lukigura and Wami. The Kinyasungwe River with its headwaters in the arid areas of Dodoma is the major river that drains the upper catchments of the sub-basin. It flows south-east to discharge into the Mkondoa River with the latter river's headwaters in the southern Ukaguru Mountains. Rivers in the Kinyasungwe drainage are predominantly seasonal and typically flow only between November and May. Similarly, the Mkondoa River flows south-east, joined by its major tributaries of Lumuma and Mdukwe, which drain the Rubeho Mountains, to discharge into the Mkata River (with its headwaters in the eastern Rubeho). The Mkondoa drainage contributes the highest volume of flows to the sub-basin via mostly perennial rivers. The Mkata River flows northeast through the Tendingo swamps and is joined by the Tami River and Kisangata (which drain the eastern Ukaguru mountains) to form the Wami, about 16 km from Wami Dakawa. Rivers of the Mkindo and Diwale drainages arise in the Ngurus, are mostly perennial and drain the Turiani plains and wetlands and join the main stem of the Wami. The main Wami River and its tributaries the Tami and Kisangata Rivers are mostly perennial systems. The only tributary draining the Nguu Mountains, River Lukigura, joins the Wami River some 47 km downstream of the confluence with Diwale. The Lukiguara drainage has relatively small catchments and rivers consequently are predominantly seasonal. The main Wami river finally flows eastwards and flows into the Indian Ocean at Saadani.

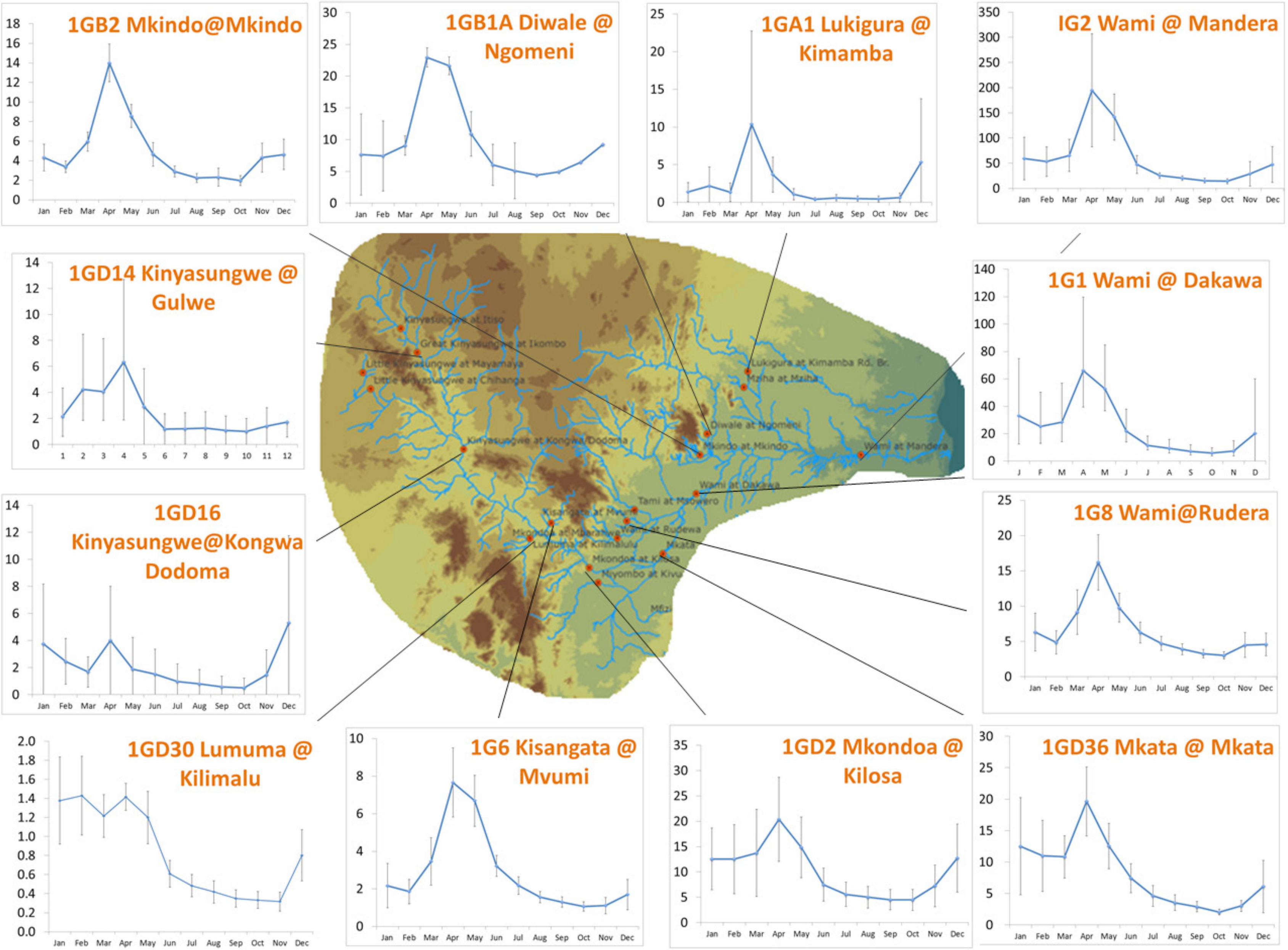


Schematic diagram of the Wami RIver and its major tributaries.

Flows:

Seasonal flows like rainfall are not uniform across the sub basin. Many rivers are intermittent and ephemeral during the dry season and experience high flows during periods of heavy rainfall. Many large rivers in the sub-basin such as the Wami, Mkata and Mkondoa (and a few small rivers) are perennial while others like the Kinyasungwe and many small rivers are ephemeral. Long-term average monthly flows from select sites suggest that the Wami River sub-basin experiences a transition pattern of intra-annual flow variation between the bi-modal (two peak periods) regime in the north and the unimodal (single peak period) regime in the south. All sites have a defined peak during the long rains and a second smaller peak in larger catchments during the short rains. The lowest flow periods of the year are typically in October for all sites, whilst low or no flow periods extend longer for seasonal rivers like the Kinyasungwe and Lukigura (WRBWO 2008a)

Wami River: Monthly flow (m³/s) averaged over 1950-2010



Ruvu River System

The Ruvu originates as fast-flowing streams in the Uluguru mountains where its tributaries Mgeta and Ruvu drain the south side and the Ngerengere drains the north. This stretch of the river with gallery forests lies 220-270 km upstream from the mouth of the Ruvu. The Ngerengere has been dammed to create Mindu reservoir for water supply to Morogoro. As the Ruvu descends to the foothills, it flows for about 20 km on a less steep gradient with less frequent rapids, larger pools and sandier substrate along with some marshy areas such as the Gonabis wetlands. The middle reaches (90 – 200 km upriver) have a low gradient and wider channels with steep banks fringed with aquatic vegetation. The river is characterized by large meanders and small islands. The substrate is finer and ranges from rock to silt with reed cover and in-stream sand bars. During the rains, the main river channel floods its banks and four extensive floodplains are formed: between the estuary and the village of Ruvu, around the Dar es Salaam – Morogoro road Bridge, one below Kidunda village and the fourth is the 250 km2 Gonabis, between the confluence of Mgeta and Ruvu. It is here that the floodplains are generally silt laden, and used for rice and maize farming with oxbow lakes/pools used for fishing, livestock and household use. The lower reaches/estuary lie from the sea to 90 km upriver. The estuary is strongly influenced by the marine environment up to 23 km inland. The salinity fluctuates through the tidal cycle and seasons. The highest salinity is during the spring high tide, during the low rain season substrate varies from sand to mud and categorized by 2,123 ha of mangroves, as described in the Estuaries section. Source IUCN 2010.

Schematic diagram of the Ruvu River and its major tributaries

Coastal Rivers

Numerous small rivers drain the coastal plane and flow into the Indian Ocean south of the Ruvu watershed. These rivers are Mkusa, Mpiji, Msimbazi, Kizinga, Mzinga, Mbezi and Luhute. Dar es Salaam City has 4 of the major coastal rivers - Mpiji, Msimbazi, Mzinga and Kizinga (JICA, 2005). Three of the coastal rivers (Mzinga, Kizinga and Msimbazi) are perennial and the Mpiji River is seasonal.

Msimbazi River: 35 km in length, the Msimbazi has a catchment area of about 289 square kilometres. Headwaters lie in Pugu forest Reserve and are joined by Sinza, Ubungo and Luhanga tributaries. It is an important water resource for Dar es Salaam and is used for drinking, bathing, support for agriculture, industry, and as an environmental buffer. However industrial effluent and illegal sewage discharge threaten the Msimbazi ecosystem, with heavy metal contamination a particular concern even for irrigation of small-scale vegetable gardens.

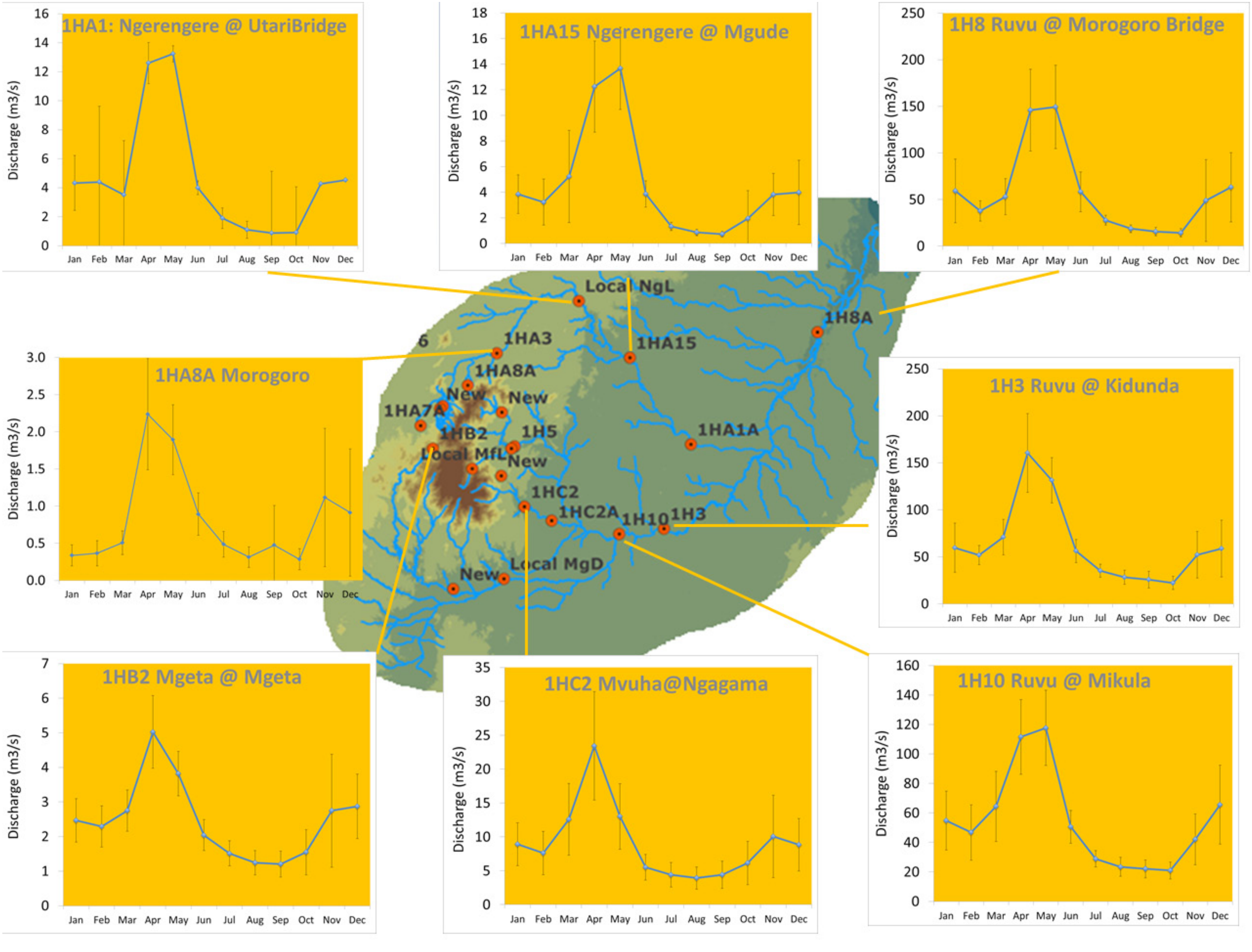
Kizinga and Mzinga rivers: originating in the Pugu/Kisarawe hills with sandy bed sediments favouring infiltration which recharges the ground water sustaining flow during the dry season. The rivers flow in the north-east direction to the Indian Ocean. Kizinga has a total length of 17.5 km and a catchment area of 432 square kilometres, Mzinga has a total length of 10.4 km and a catchment of 41 square kilometres. The water in the Mzinga and Kizinga rivers meets domestic standards for drinking water. Mzinga is not perennial while Kizinga flows throughout the year and support domestic water supply in the Mbagala area

Mpiji River: The Mpiji River forms the northern border between Dar es Salaam and Coast Regions. It is a seasonal river stretching to about 12.7 km long with a catchment of 52 square kilometres. Despite the growing city towards Bagamoyo, the river is still less polluted compared to the other rivers draining the city centre.

Other smaller rivers

There are also small and seasonal rivers and streams including Tegeta, Mbezi, Mlalakuwa, Kijitonyama, Sinza and Tabata. These are essentially temporal in nature. rivers largely serving as a drainage network for Dar es Salaam city.

Ruvu River: Monthly flow (m³/s) averaged over 1950-2010



5.2 Groundwater Resources and Hydrogeology

Groundwater is usually safer for domestic consumption as compared to surface water which is more susceptible to pollution. However, groundwater can get contaminated from open wells and pit latrines in rural areas as well as leaking undergound fuel storage tanks. The use of groundwater for irrigated agriculture is also rising; while groundwater constitutes an available source especially in dry years, high rates of extraction that exceed natural groundwater recharge can rapidly become unsustainable.

Aquifers in the basin are categorized into three types; Quaternary aquifers(unconsolidated sedimentary layers), Tertiary aquifers (semi – consolidated layers) and Cretaceous Jurassic and Precambrian aquifers (water in fissure of consolidated sedimentary layers, granitic rocks and metamorphic rocks).

Quaternary aquifers

Dar es Salaam and Coast Region, the thickness varies from 1 – 100 m and more.

Mgeta plain, situated southeast sides of Uluguru Mountain and widely distributed along the Wami and Kinyasungwe Rivers with its tributeries.

Tertiary Aquifers

Tertiary aquifer is distributed from the hills of Mkuranga district in the east to the Chalinze ward of Bagamoyo district. The sediment consists of interbedded sandy clay and clay sands with minor lenses of pure sand or clay (Temple, 1970). In the western part of Tertiary aquifer, which is situated in the west side of the Ruvu River, no lithologically defined aquifers were found, although discontinuous sandy zones were encountered (CIDA, 1979). In this area, it was suggested that the groundwater is recharged from the Ruvu River.

In the areas from east side of the Ruvu River to the west side of the Mzinga River, it was suggested that this area is the recharge zone (CIDA, 1979). In the areas from the east side of Mzinga River to areas eastward, Neogene deposits are typical and consists of interbedded sandy clays and clayey sands sometimes cemented in irregular bodies to form weak sandstone. Neogene sediments in this area are separated by depressions. The Kimbiji aquifer, which is now being assessed by DAWASA is a deeper part of the eastern part of the Neogene aquifer.

Mesozoic to Paleozoic Aquifers

Jurassic Formation

DGIS (1980) reported that three formations distributed in Jurassic formation that are Jurassic Sandstone, Jurassic Limestone and Station Bed. The geology and groundwater information of these three formations are as follows.

The Jurassic Sandstone, which is distributed in Ngerengere, is predominantly medium-coarse, poorly sorted, firmly cemented, feldspathic sandstone. The sandstone layer contains water- bearing zones. The groundwater mainly flows along faults and fractured zones. The fault zone offers fair possibilities for successful boreholes with moderate to low yields between 24 and 300 liter/min and acceptable salinity.

The Jurassic Limestone, which is distributed in the Kidugallo area, is groundwater-bearing and offer fair possibilities for boreholes. The yields of exiting boreholes are between 72 and 144 liter/min. The electric conductivities in the limestone are between 120 and 190 mS/m.

The Station Bed consisting with siltstone, fine sandstone, massive medium to coarse grained sandstone and argillaceous limestone overlies the Jurassic limestone formation. According to the drilling result of four boreholes reported by DGIS (1980), it is reported that there is no possibility of development of groundwater due to high salinity of water, and primary permeability is very low. Groundwater flow principally occurs along bedding planes and fractures. According to DGIS (1980), the Karoo formation in southwest is water-bearing and most probably offer fair prospects for boreholes with low to moderate yield between 150 and 306 liter/min and specific capacities between 6 and 102 liter/min/m.

Karoo Formation

The Karoo formation is distributed in eastern foothills of the Uluguru Mountains, and consists of very coarse sandstone, green shale, fine sandstones and siltstone. The rocks are firmly cemented and thus have a very low porosity and permeability.

Precambrian Aquifers

Granite

Granite and migmatite are distributed in the western side of the basin, where Dodoma Urban, Bahi and Chamwino districts are located. In this area, the graben and horst formed by the faults with the direction of NNE-SSW are distributed. The groundwater is mainly distributed in the weathered and fractured part. The Chenene Hill located in the northern edge of the Granite, is the recharge area of the groundwater in Makutupora basin (Shindo, 1994)8. The median of yield is 305 liter/min and the value of electric conductivity is 1,360 μS/cm. The majority of high yielding wells are located in Makutupora basin, which is the main water source for the capital city, Dodoma.

Metamorphic Rocks

Metamorphic rocks are extensively distributed in Wami/ Ruvu Basin. The meta-igneous and sedimentary rocks are distributed from Kilosa district to southern part of Kondoa district in Dodoma region. In the northwestern part, the graben and horst are formed by NNE-SSE direction fault. The groundwater mainly exists along the fault. The median of the yield in the area of metamorphic rocks is 150 liter/min.

The composite metamorphic crust domain and granulite, gneiss and migmatite are distributed in the north part of Morogoro region, southern part of Tanga region and north of Coast region. The fault is not well developed compared to the meta-igneous and sedimentary rocks described above. The median yield in this formation is 62.8 liter/min, which is less than half of that of meta-igneous and sedimentary rock. The high valu

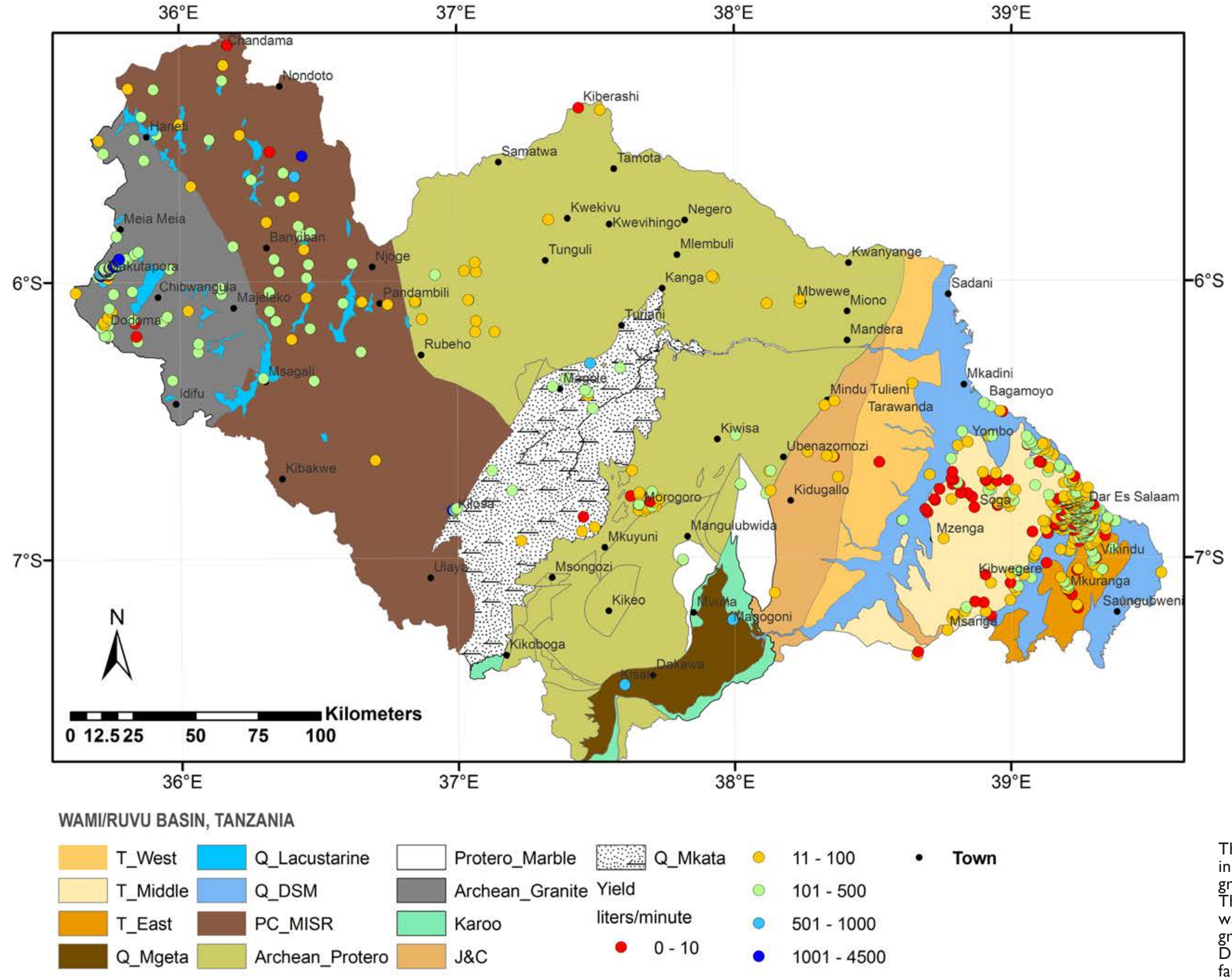
Marble

Marble is distributed in the eastern side of Uluguru Mountains and constitutes a groundwater bearing formation. The groundwater in a karst area mainly moves along solution openings and zones of fracture and fault (DGIS, 1980). The value of electric conductivity of water of spring varies from 450 to 550 µS/cm.

Source: Wami Ruvu Basin Annual Hydrological Report 2010-2011

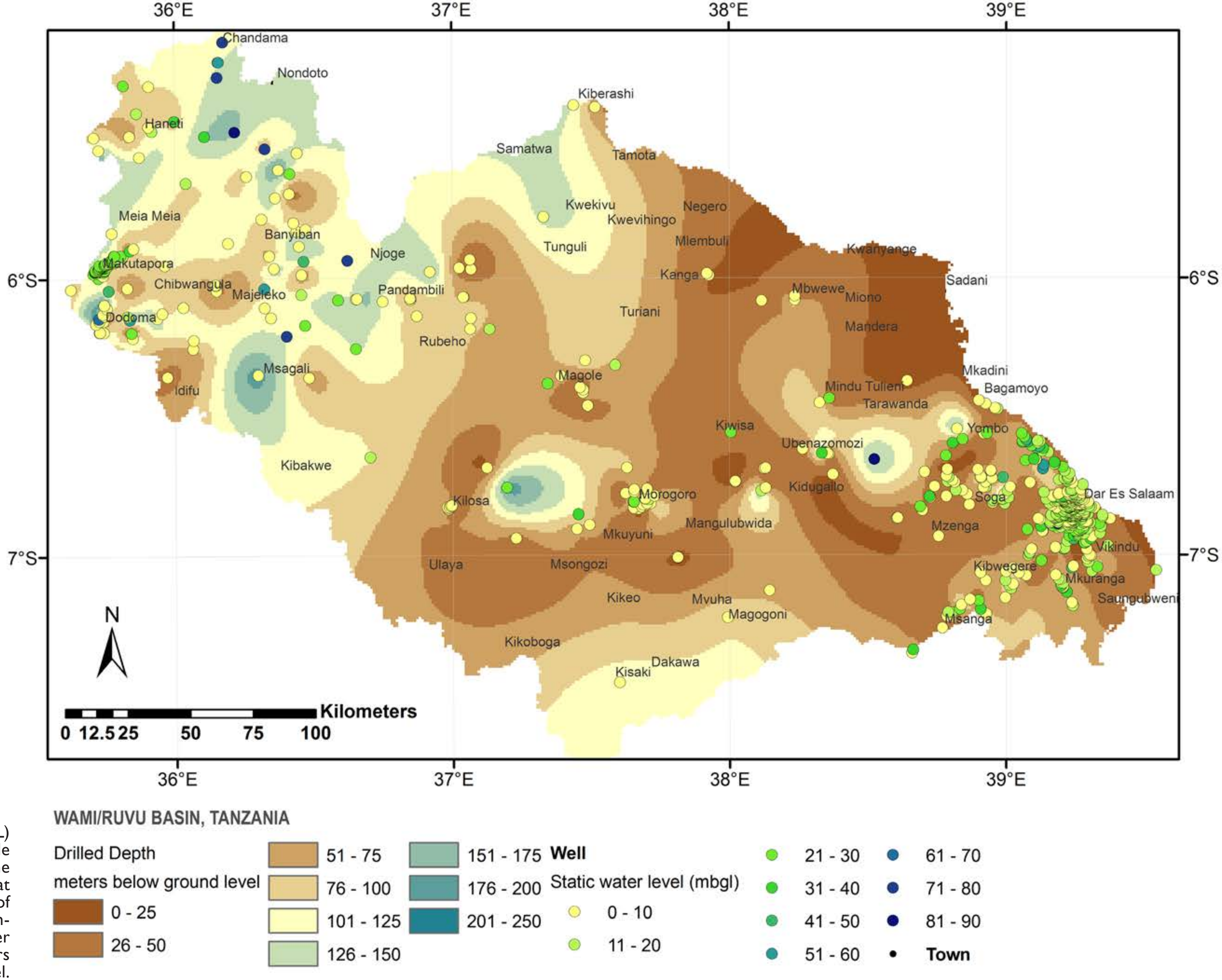
Borepump in the Mkindo Catchment, Wami River Basin.

Map_5_6: Aquifers and water yield in the Wami/Ruvu Basin



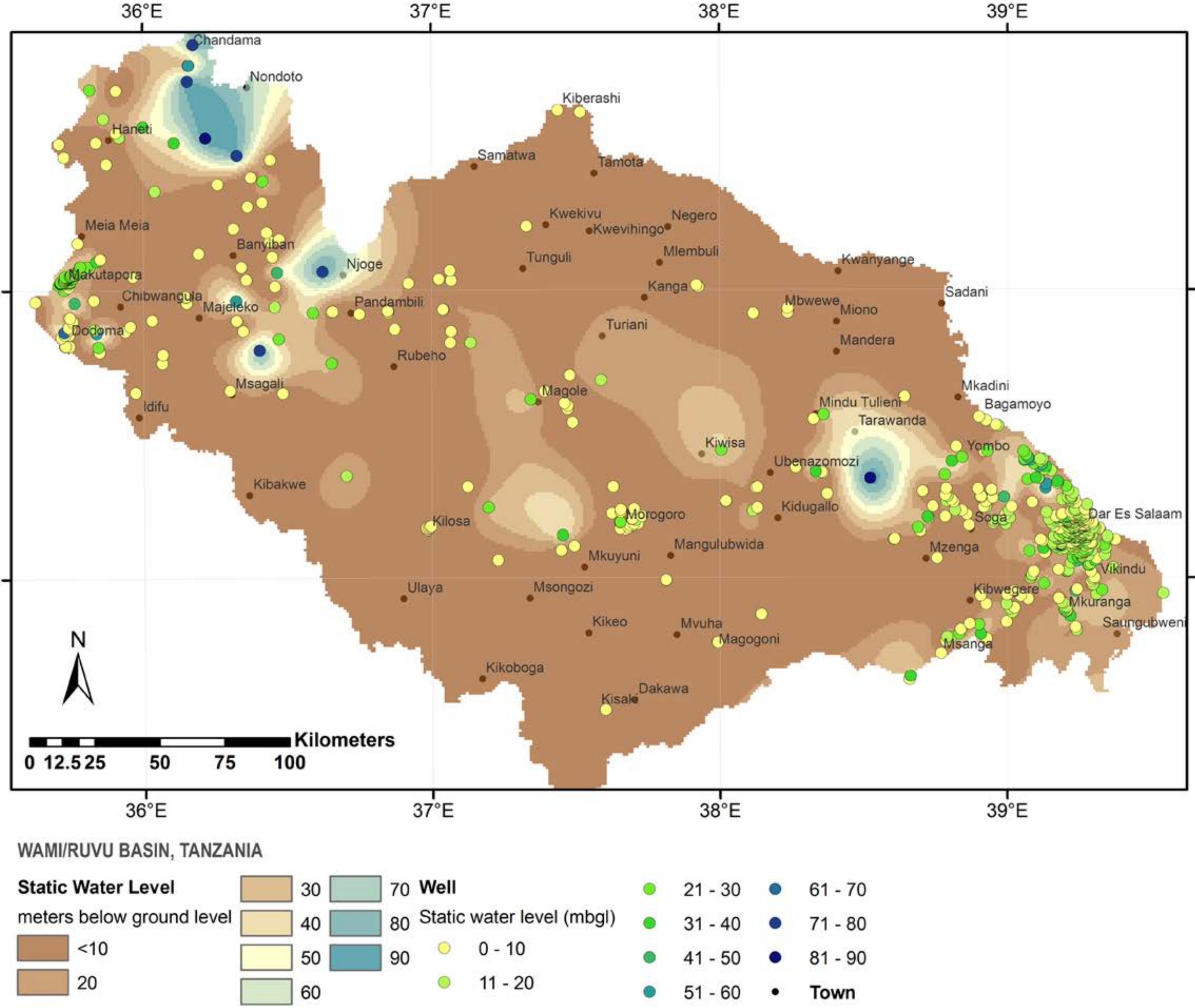
The presence of fault zones in aquifers indicates higher groundwter yield.
Thus faults increase the water-holding capacity of granitic aquifers underlying Dodoma. Refer Map 2_9 for fault zones.

Map_5_7: Drilled depth and Static Water Level in the Wami/Ruvu Basin



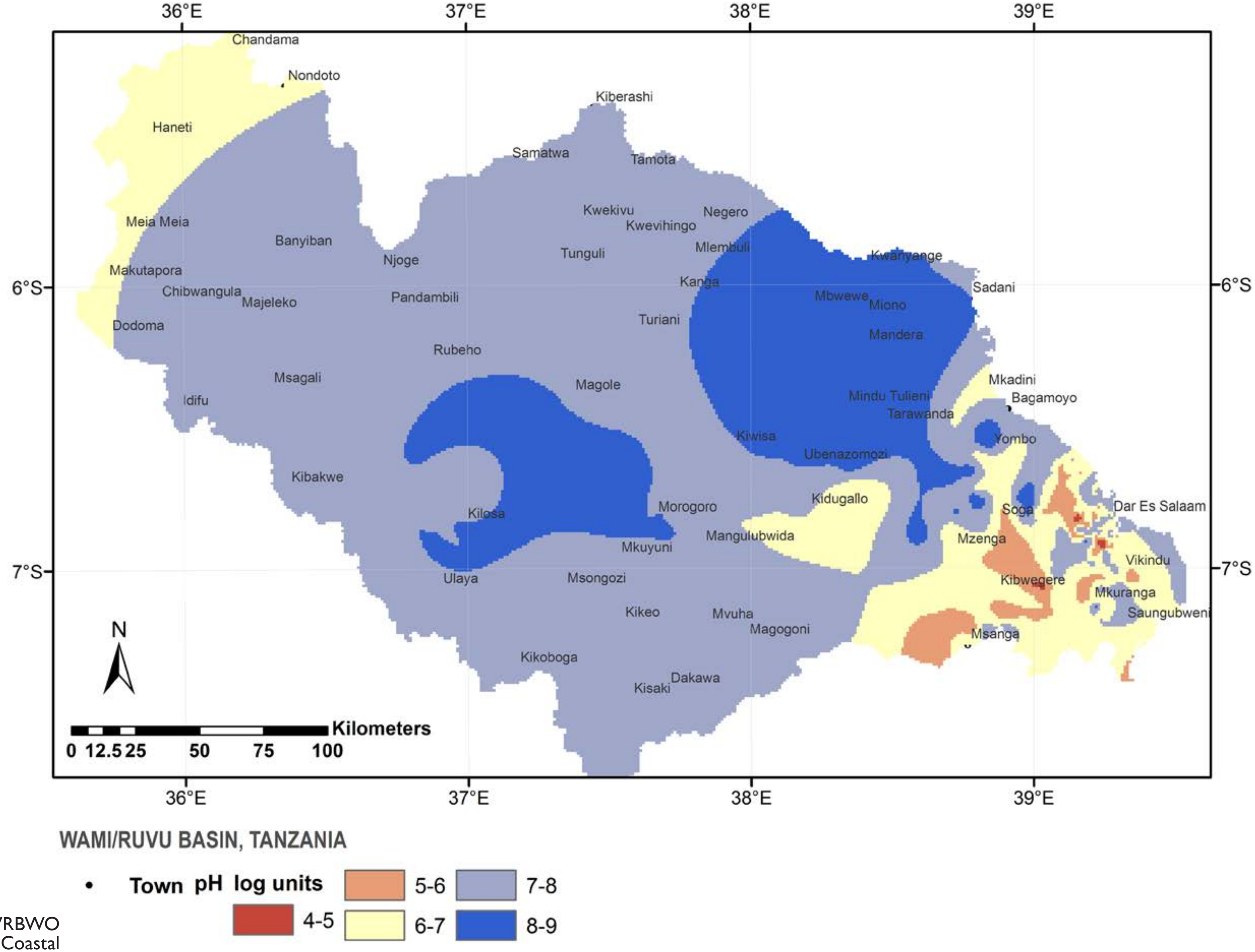
Static Water Level (SWL) refers to the water table level measured from the ground surface usually at dawn, in the absence of pumping activity that temporarily lowers the water table. Expressed in meters below ground level.

Map_5_8: Static Water Level isoclines and wells in the Wami/Ruvu Basin



Isoclines spatially extrapolate information from point readings at the wells.
The accuracy of this extrapolation depends upon the density of wells as well as how evenly are the wells spread out. Hence isoclines should be viewed only as a rough idea with caution.

Map_5_9: pH in the Wami/Ruvu Basin



Data Source: WRBWO Annual Hydrological Report 2012. Coastal groundwater is more acidic as compared to groundwater further inland. Well locations are shown on the maps to indicate sampling locations. Care should be used in inferring data in regions with a low density of sampling locations.

Section 6:

Water resources use

Small water users—rural villages (domestic, drinking, washing, livestock, small agriculture)

A girl collecting water from a perennial stream for construction of a cement schoolhouse; this water is usually not used for drinking as this village has a borewell handpump.

Laundry by a running perennial river

Borewell in village used primarily for drinking and cooking, with surplus drained away to nearby vegetable beds that are otherwise rain-fed

Hillslope agriculture is mainly rain-fed with occasional small irrigation channels dug from spring outlets

River fish that form an important protein source for local communities are sensitive to seasonal fluctuations in water level; excess water abstraction or sudden releases can negatively affect fish populations

Toilet block requires water for flushing and washing.

Pastoralist communities are nomadic owing to the grazing needs of their livestock. However, increased settling of lands for agriculture is decreasing cattle access to water.

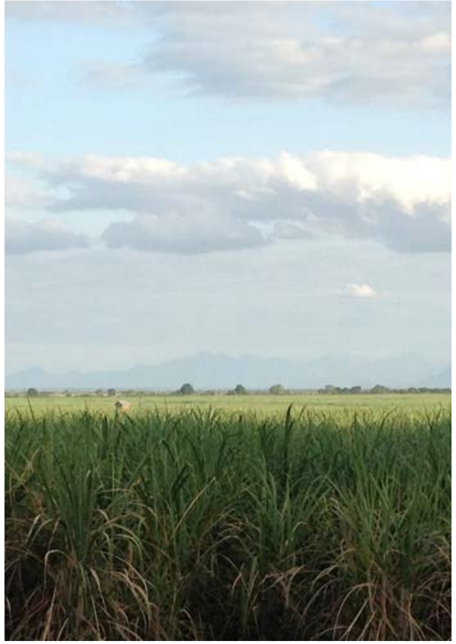
Large water users-irrigated agriculture, industry, urban water supply, energy and transportation


Industries constitute a large water user. Shown is a brewery that needs a dependable water supply for the product as well as the manufacturing process.

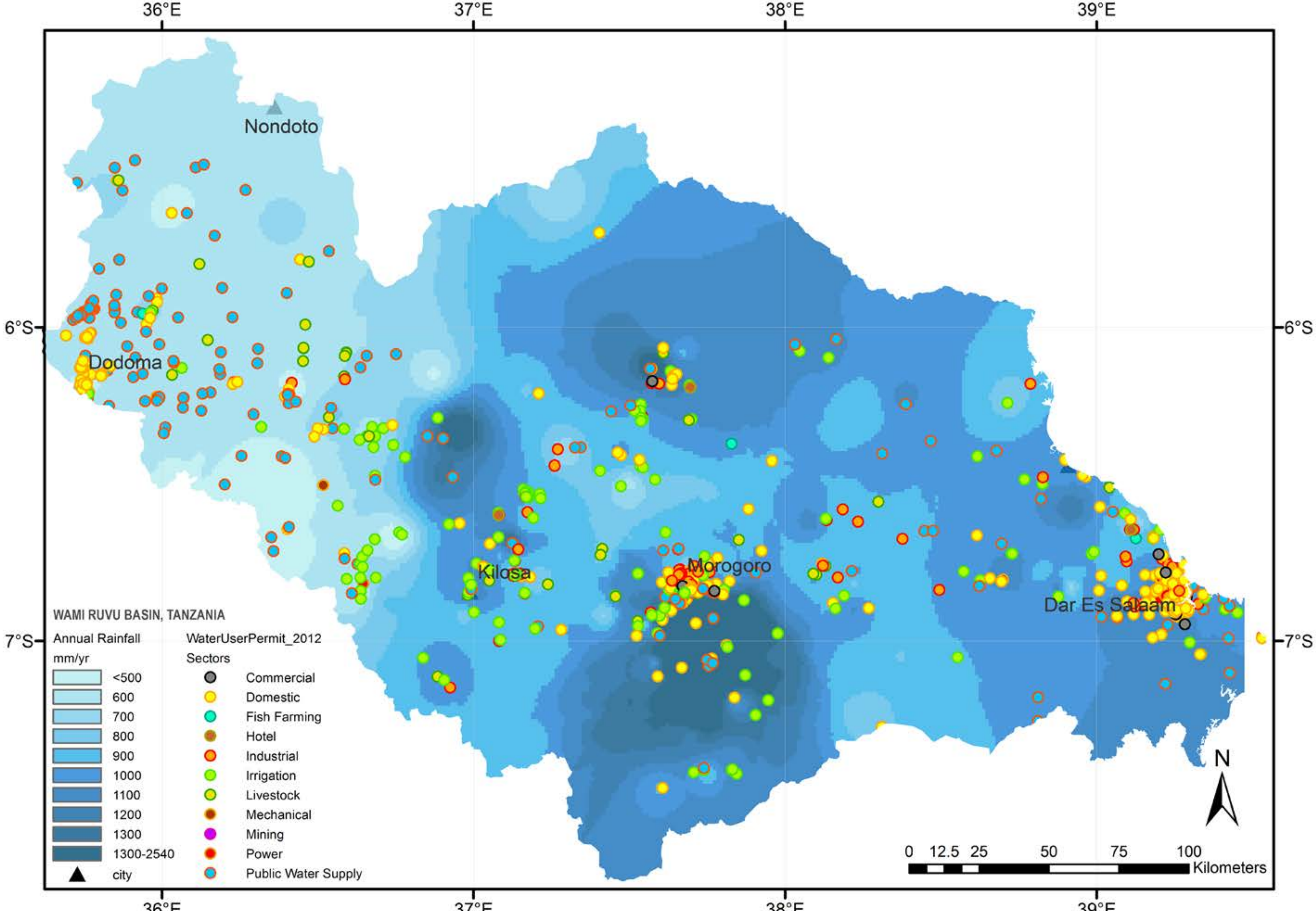

Tanneries for treating and manufacturing leather also require effluent treatment systems to avoid toxic chemicals from entering water.


Irrigated agriculture using surface water diversion


Urban areas have high domestic and industrial water demand, with added commercial, institutional and transport sector demand as well


Large sugarcane farm uses rainfall, surface water from reservoirs and groundwater in the dry season

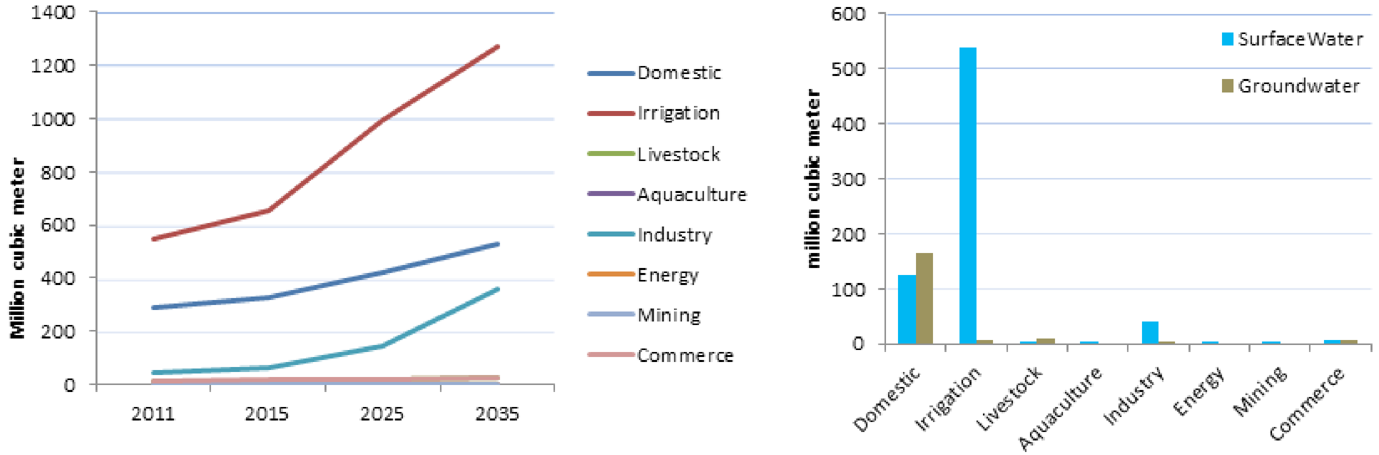
Map_6_1: Water user permit locations in the Wami/Ruvu Basin in 2012



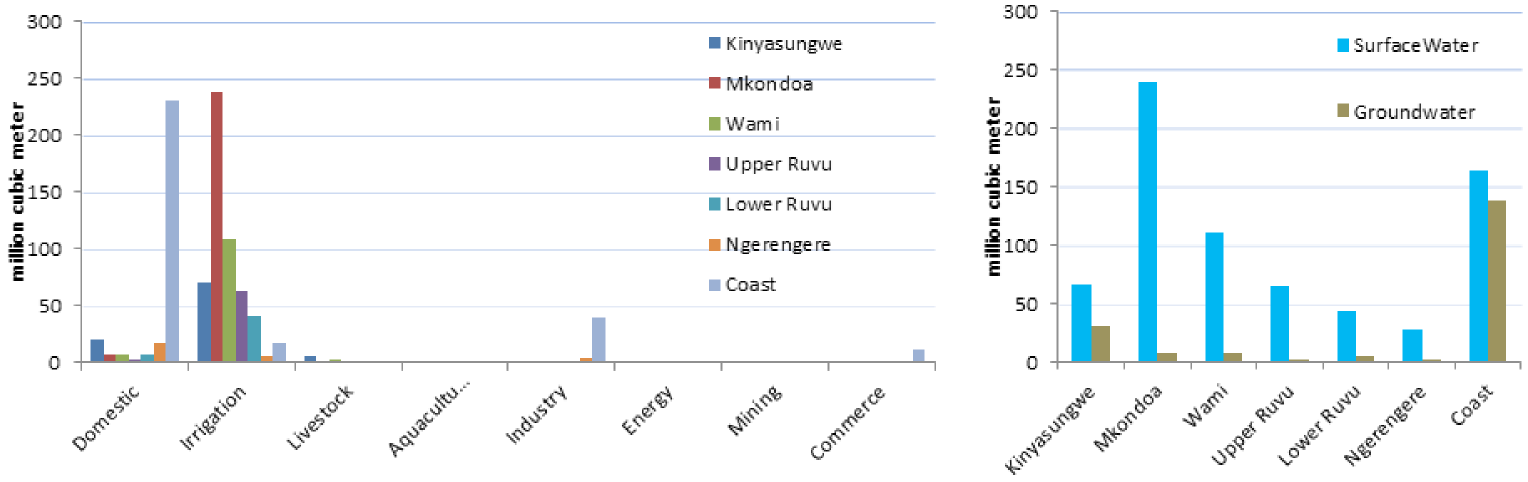
The largest use of water in the Wami/Ruvu Basin is surface water for irrigation, followed by surface water and groundwater for domestic consumption (JICA 2013). Industry and livestock are next. In comparison to the big two uses (irrigation and domestic use), other sectors such as energy, mining, aquaculture/fishery ponds and commercial/tourism are small at the basin scale.

Water use is distributed throughout the basin. The largest amount of irrigation demand is in the Mkondoa sub-basin, followed by Wami, Kinyasungwe, Upper and Lower Ruvu sub-basins. Domestic demand is highest in the Coast subcatchment that includes the Dar es Salaam metropolitan region. Industrial water demand is also the highest in that region.

Projected demand: industrial and domestic demand are the two sectors that are forecast to grow the most, followed by irrigation (JICA 2013). The share of groundwater will increase. Even so, irrigation and industrial efficiency will have to improve to meet water needs at the subcatchment and basin level.

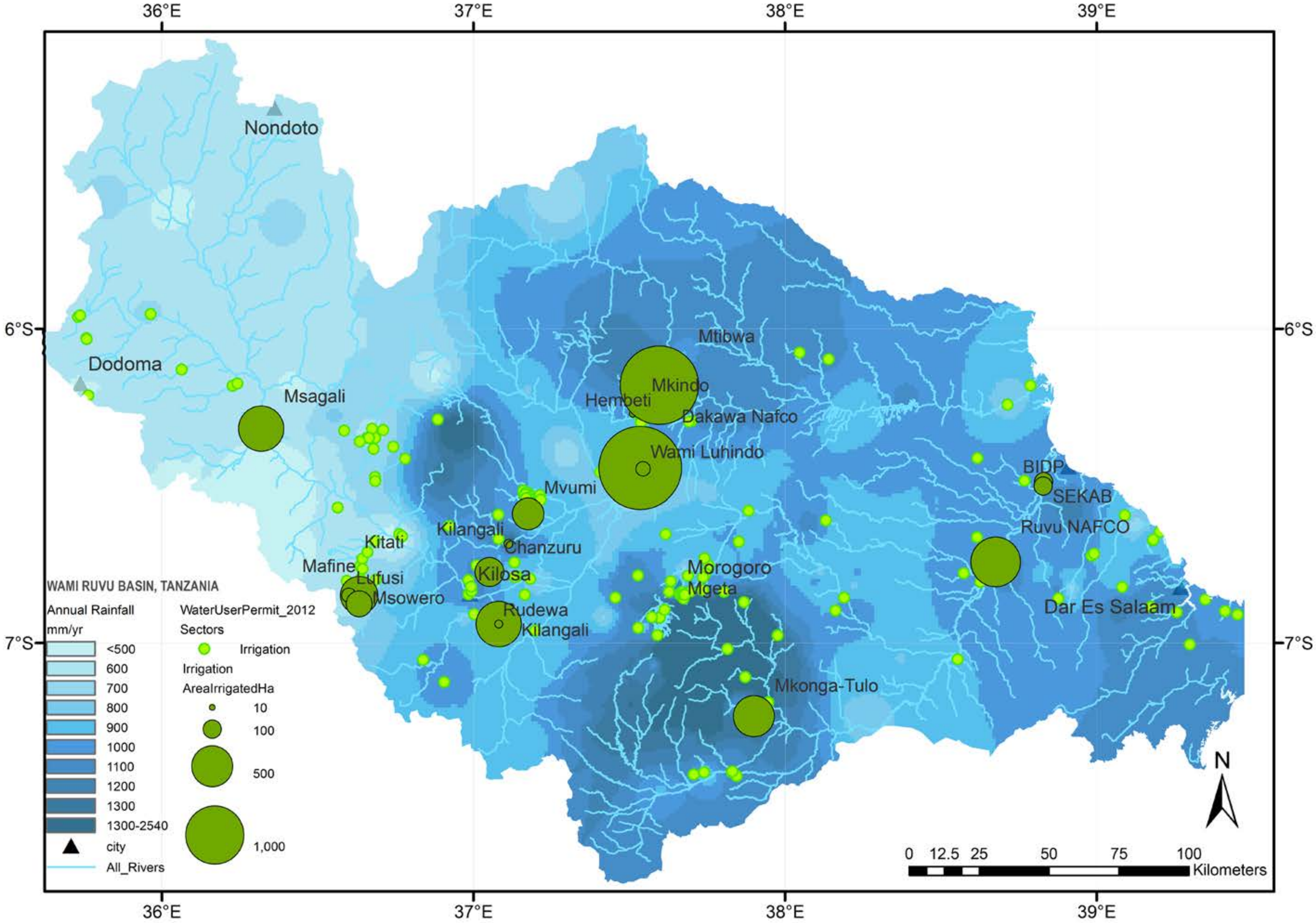


(Left) Water use by sector in 2011 and projected water demand upto 2035 (Source JICA 2013). (Right) surface water and groundwater utilization by each sector.

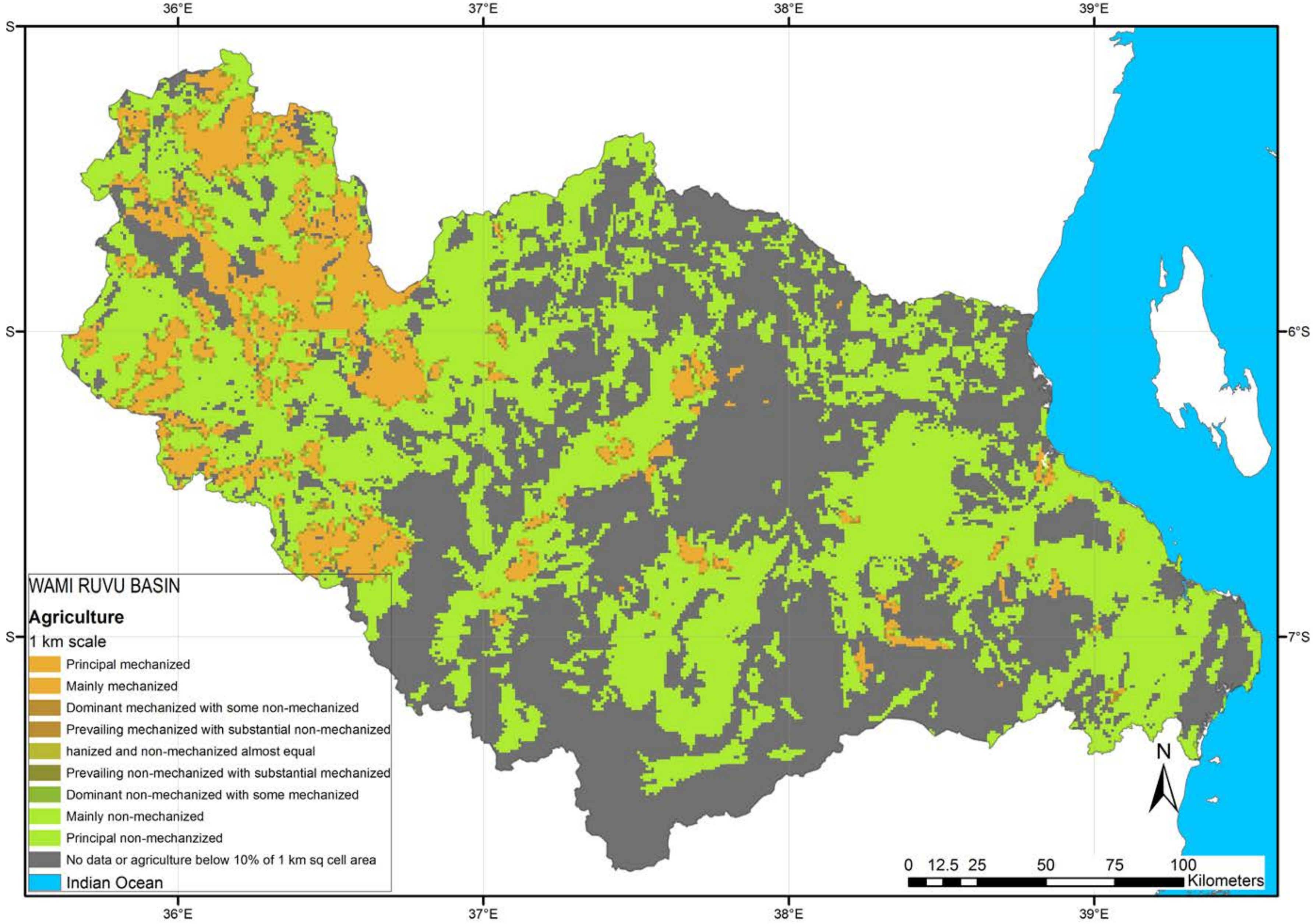


(Left) Water use by sector in each subcatchment in 2011 (Source JICA 2013). (Right) surface water and groundwater utilization by each subcatchment.

Map_6_2: Irrigation user permit locations as of 2012



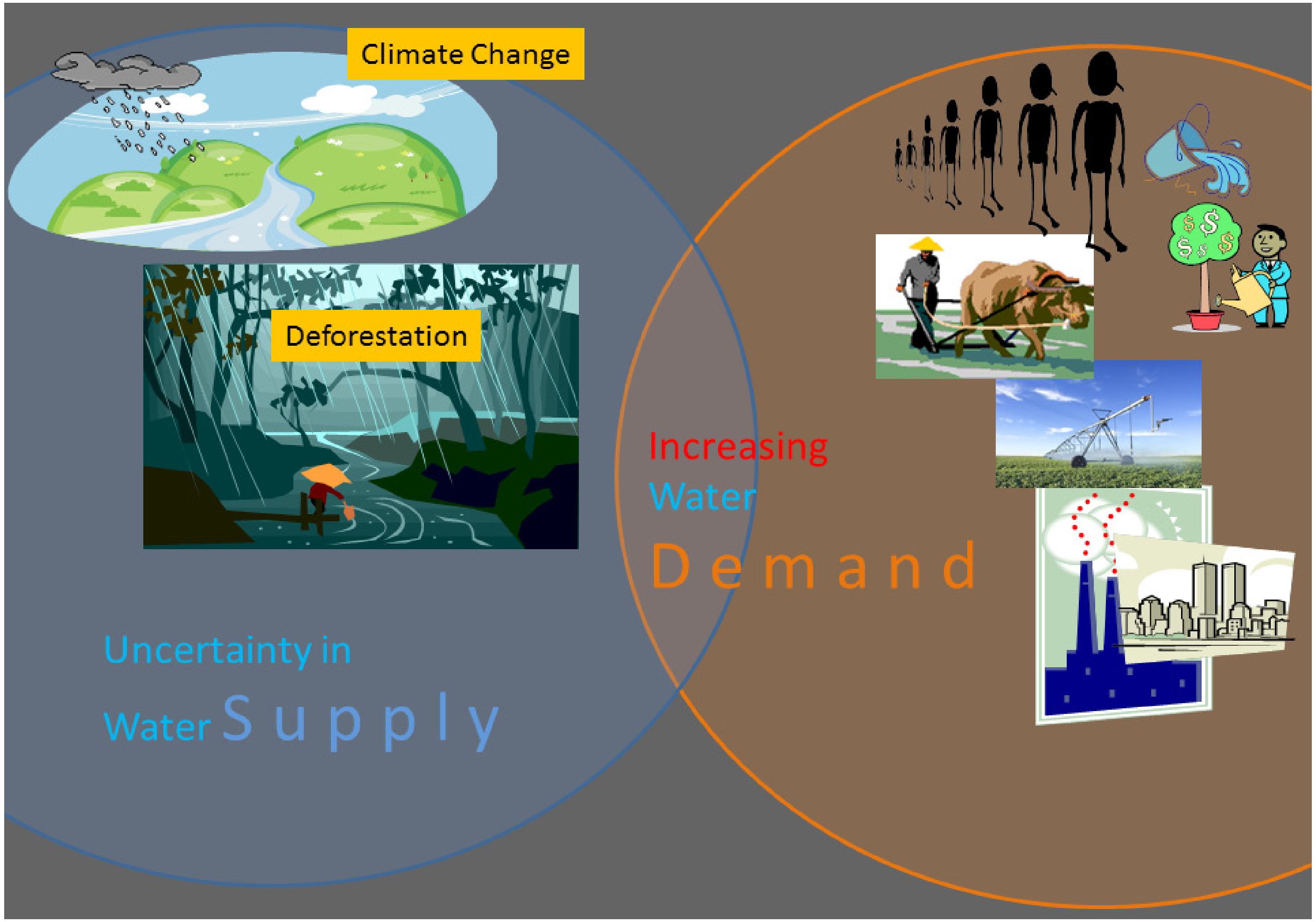
Map_6_3: Mechanized and non-mechanized agriculture



Section 7:

Vulnerability of water resources

Like much of the world, the Wami/Ruvu Basin faces increasing demands for water together with an increasing level of uncertainty in water availability, as illustrated to the right. The table below summarizes the major areas or factors of vulnerability, along with the degree of control that stakeholders in the Basin have over a particular factor. For instance, there is little control over uncertainty in precipitation caused by climate change because the latter operates on a regional to global scale.



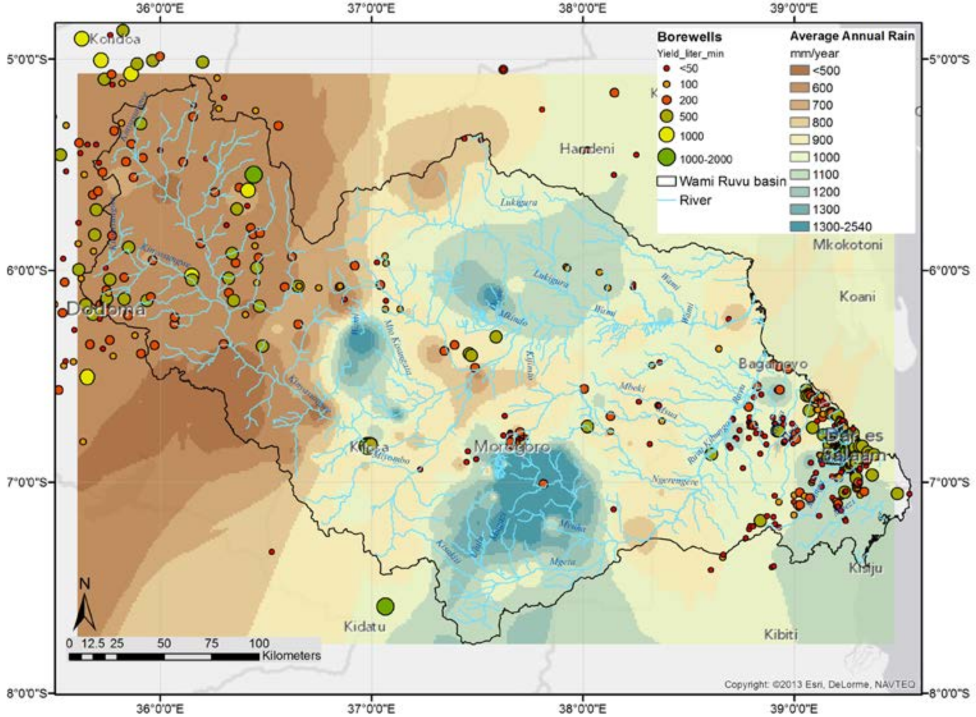
Water availability is affected by both the uncertainty in water supply as well as increasing water demand.

Vulnerability Factor	Control	Strategies
Uncertainty of rainfall onset and distribution; increased by CLIMATE CHANGE	No	Increase water storage on landscape (maintain forest and wetland cover); Basin-wide Water Monitoring Program involving communities; early flood warning systems; maintain water supply infrastructure in working order; develop sector-specific adaptation plans, eg agriculture, industry, livestock, power, ecosystems
DEFORESTATION—lowered water retention and flow regulation—flash floods and earlier drying up of springs/rivers	Yes	Protection of primary forest as reserved forest/national park; reforestation; soil and water conservation on steep slopes; awareness generation of role of forests in rural schools
WETLAND drainage and loss—lower water storage on landscape - flash floods and earlier drying up of springs/rivers	Yes	Protection of wetlands with national park status; prevent further drainage of wetlands; artificial wetland creation and management for domestic wastewater treatment
Increasing WATER DEMAND—population, growth, per-capita consumption, globalization	Partially	Water conservation encouragement by tiered pricing and awareness generation; water reuse plans for municipal/industrial wastewater; groundwater monitoring
Deteriorating WATER QUALITY- pollution, lower flow, deforestation, wetland loss	Yes	Maintain forest cover on steep slopes; manage wetlands; riparian buffers along rivers; soil and water conservation on farms; industrial /domestic effluent treatment; enforcement of laws; awareness
SEA LEVEL RISE — Salinization of coastal aquifers	Partially	Ensure adequate freshwater inflows into estuaries; coastal aquifer monitoring program

7.1 Groundwater use

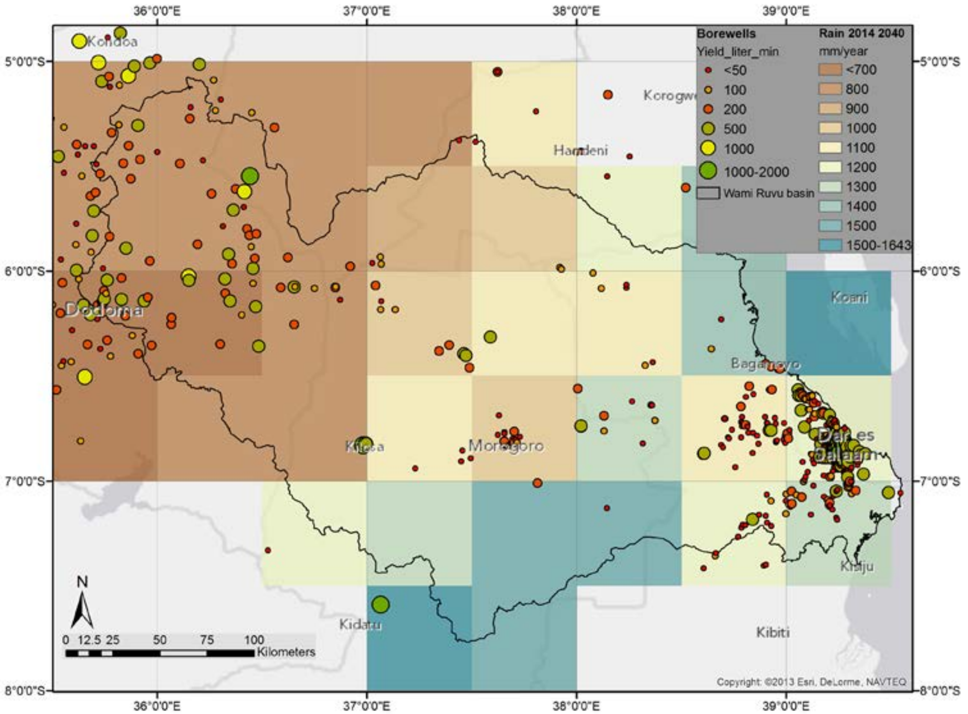
Regions of high groundwater extraction in the Wami/Ruvu Basin, 2012

Map_7_1



Borewell locations along with pumping capacity against a backdrop of average annual rainfall (1950-2010).

Map_7_2



Borewell locations and yields against a backdrop of projected annual rainfall (2014-2040) at a 50km grid. Data Source for rainfall projection: ClimateWizard.

The majority of borewells in the Wami/Ruvu Basin are clustered in two regions:

1. the semi-arid Dodoma region with very low rainfall (< 500 mm/yr): High rates of groundwater extraction in the arid region can lead to falling water tables, especially if the extraction exceeds natural recharge as well as any subterranean flow that may happen from surrounding regions of the aquifer.

2. The coastal Dar es Salaam region: the pumping of large amounts of groundwater in coastal areas can cause accelerated seawater intrusion into coastal aquifers.

It is essential to increase the density of monitoring wells and develop a Groundwater Monitoring Program as the first step to determine and achieve sustainable amounts of annual groundwater use and recharge.

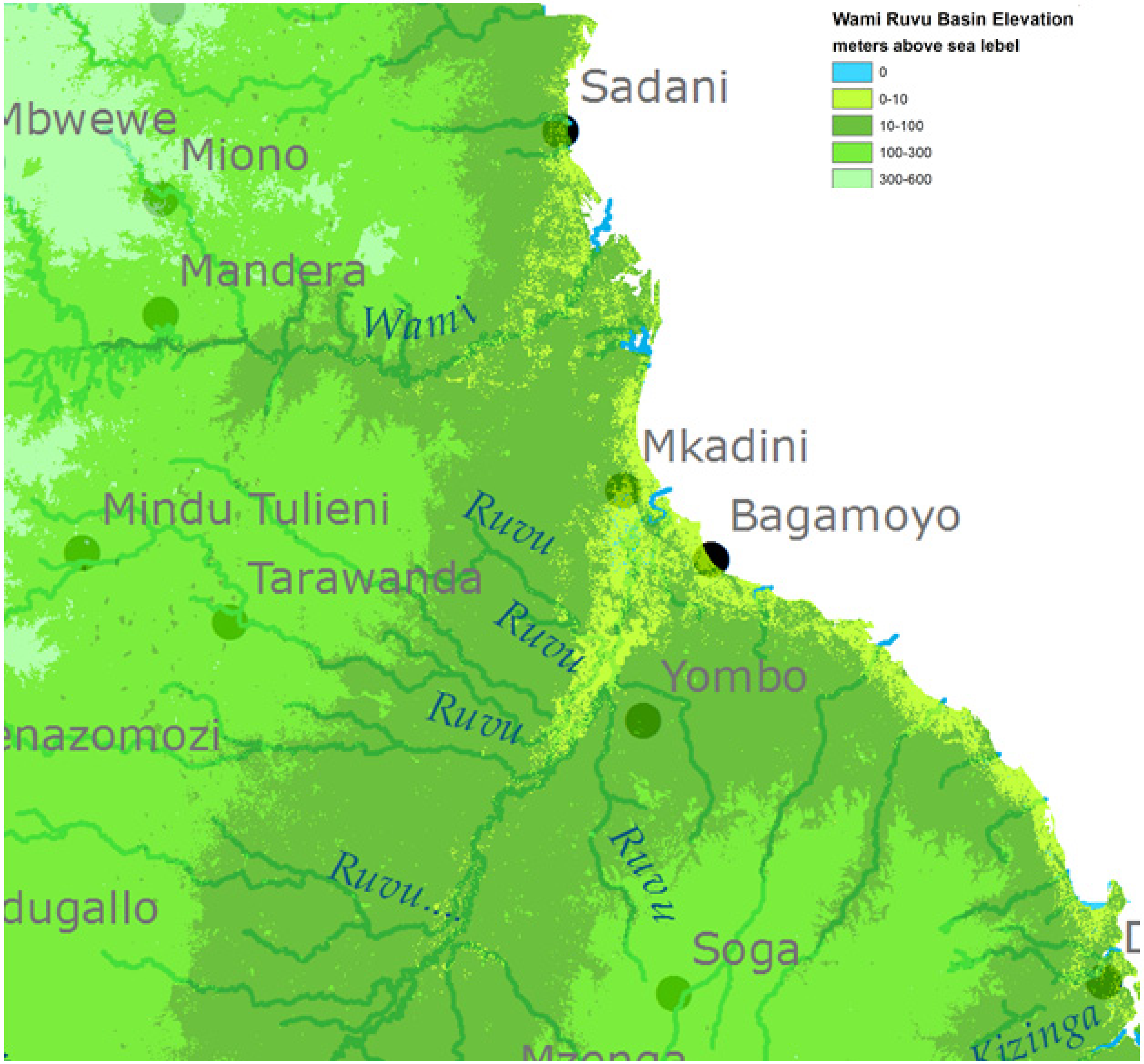
7.2 Flood-prone zones

Coastal areas and river floodplains are usually the areas with the lowest elevation on the landscape and hence are the most susceptible to flooding.

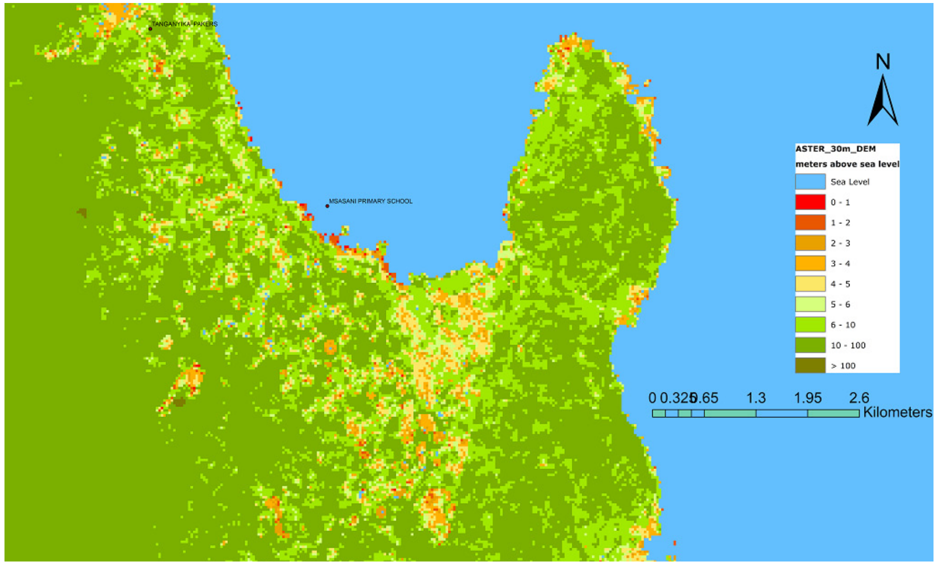
The low-lying areas extend along the coastline, as well as inland along the Ruvu river floodplain. These are the areas at higher risk of flooding from upstream discharges during heavy rains, from sea level rise and storm surges. Groundwater in these areas may also be at increased risk of getting saline on account of seawater intrusion.

The map has been created from the Digital Elevation Model ASTER-DEM 30 that is also included in the Digital Atlas of the Wami/Ruvu Basin. The Digital Atlas enables the user to zoom into any location within the Wami/Ruvu Basin to an area of resolution 30m * 30 m. The elevation scale can be changed in the DEM symbolization to display topography in user-defined ranges such as shown in the figure. Using this tool one can generate maps with user-specified elevation ranges, such as 0-1 m, 1-2 m and so on, to visualize low lying areas in those ranges.

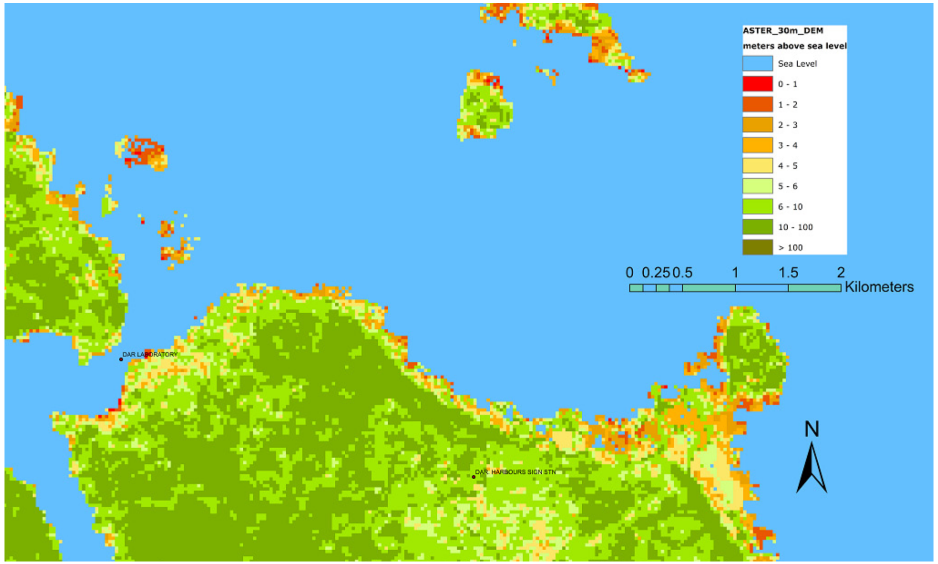
Note that such a utility is limited by the elevation accuracy of the DEM and such a map can be used to visualize the low-lying flood-prone areas, whose elevation can then be checked with a survey dataset or topographic map.



Coastal Ruvu Basin, with lowlying areas (< 10 m above mean sea level) in light green



Flooding vulnerability map for Msasani and Kinondoni, Dar es Salaam (top left). Areas in red have an elevation < 1 m above mean sea level



Flooding vulnerability map for Dar es Salaam harbour (top left) . Areas in red have an elevation < 1 m above mean sea level

Flooding vulnerability map for downtown Dar es Salaam superimposed on street map. Areas in red have an elevation < 1 m above mean sea level

7.3 Deforestation, soil erosion and changes in streamflow regime

This series of photographs are from the same catchment in the Ngurus

The clearance of primary forest for agriculture and charcoal-making leads to soil erosion into rivers and eventual furrows deepening into gullies on hillslopes The lack of any contour terraces, bunds or other soil conservation measures on the steep slopes cleared for farming are leading to high soil erosion and the eventual abandoning of farms once the thin top soil has washed off. A lack of land ownership acts as a disincentive to local farmers to invest time and labour into making these soil conservation structures; they prefer to move on and clear forest elsewhere once their farms have lost soil, typically in 8-10 years.


Clearing and burning of forest for agriculture


Rivers laden with soil


Maize farm to the left and abandoned farm to the right, with eroded gullies visible in the centre.

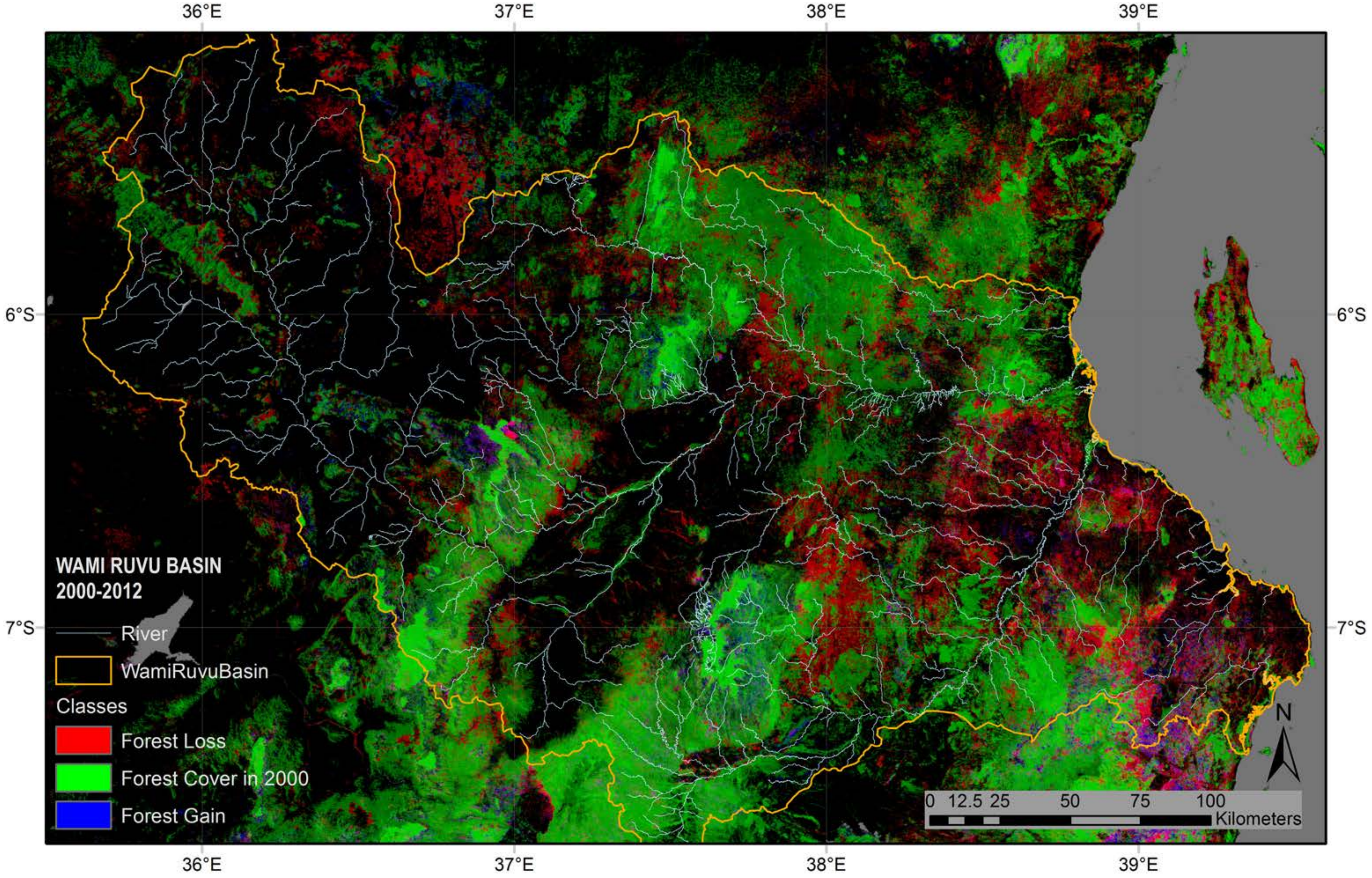

Charcoal being taken to the market

While charcoal is the main fuel source in the Wami/Ruvu Basin, and charcoal manufacture provides an income for a significant section of the population, active reforestation is vital to ensure not only the long-term sustainability of charcoal-based economy but also the hydrological and ecosystem services provided by forests.

Land Cover Change in the Wami and Ruvu Basin: 1984-2012. Source: TIME & Google Earth 2012

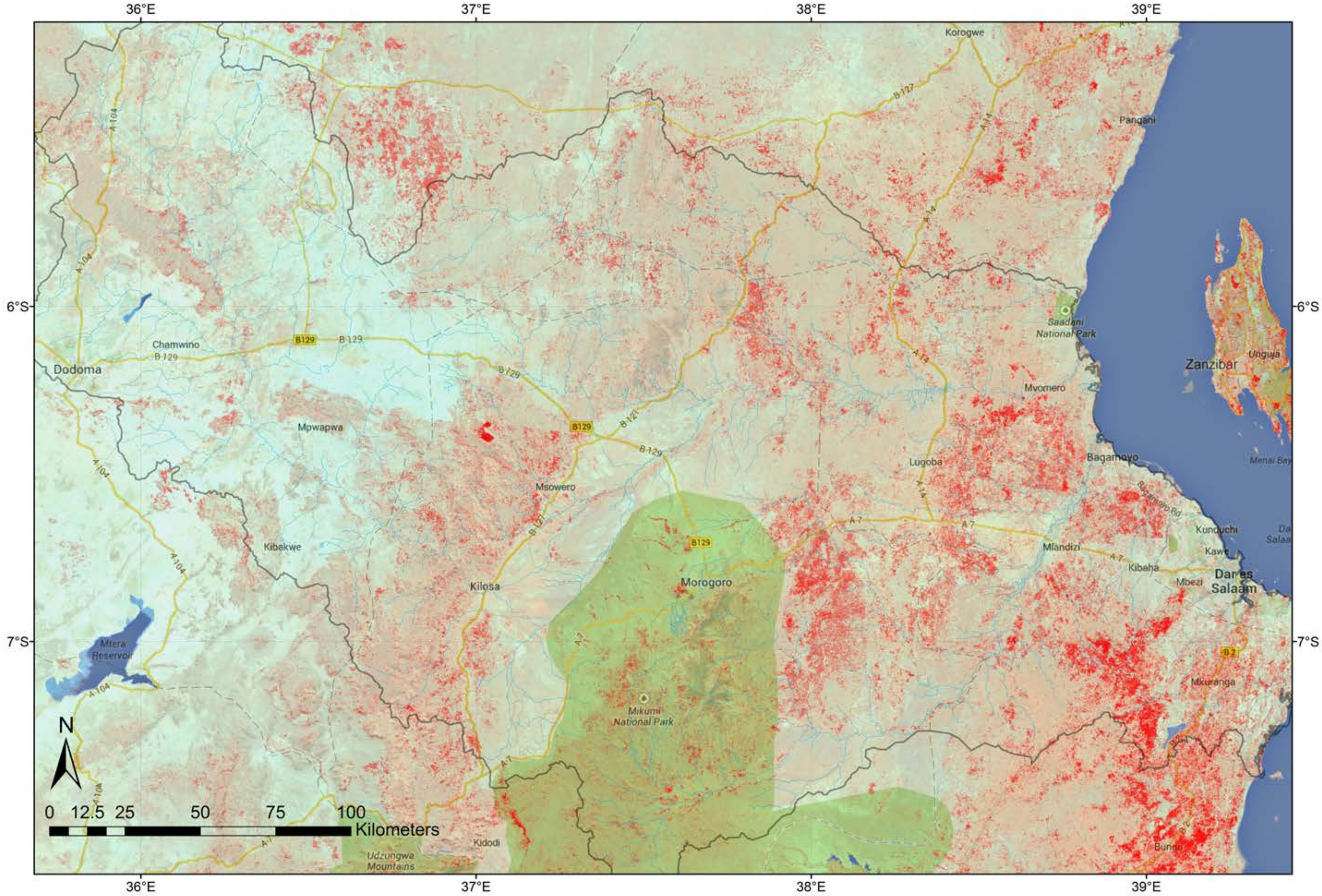
Land Cover Change (1984-2012) in the Wami/Ruvu Basin as inferred from Landsat TM satellite imagery. Top left (1984), top right (1994), bottom left (2000) and bottom right (2012). A decrease of vegetation cover (greenness) is noticed over this time period. In 2012, the main forested areas are restricted to forest reserves in the Eastern Arcs mountains (Ngurus, Ulugurus, Ukagurus and Rubeho).

Map_7_3: Forest Cover Change in the Wami/Ruvu Basin (2000-2012)



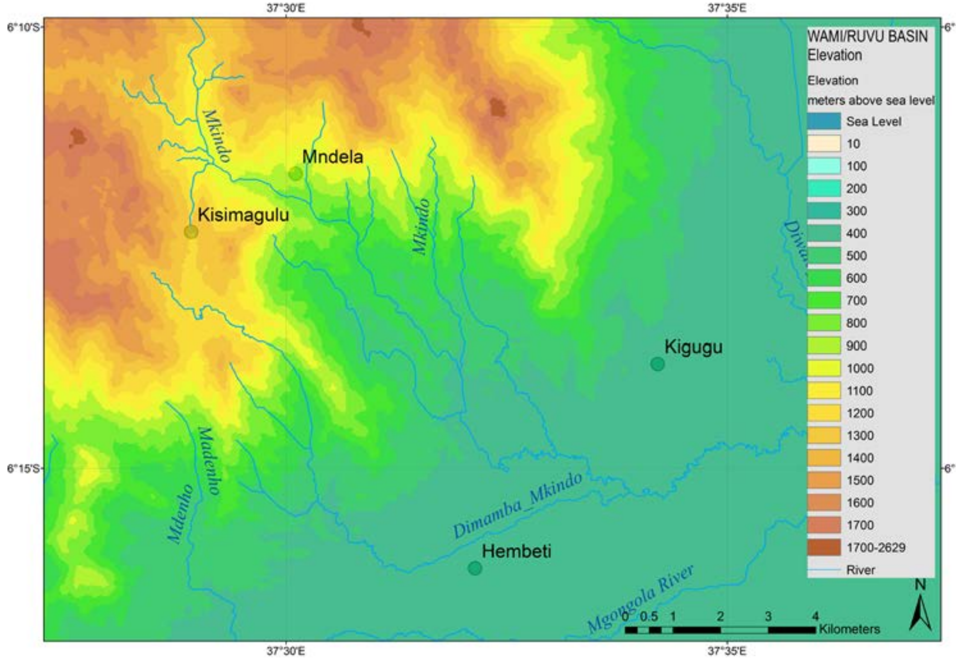
Green areas show forest cover in the year 2000), red areas denote forest loss over 2000-2012 and blue shows forest gain over the same time period. Black denotes areas with no forest cover in 2000. Forest gain is mainly from reforestation projects. Map created from classification of Landsat imagery over 2000-2012. Source: Hansen/UMD/Google/USGS/NASA

Map_7_4: Forest cover loss in the Wami/Ruvu Basin (2000-2012)

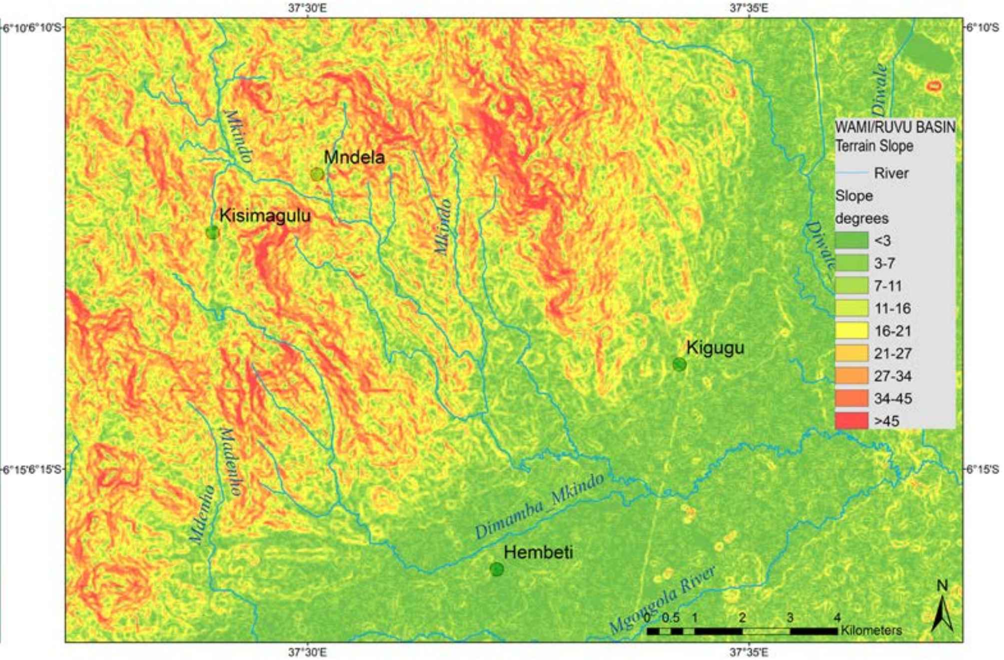


Forest cover loss is shown in red, with deeper red areas signifying high levels of deforestation. This map is based on analysis of Landsat TM satellite images over 2000-2012 (Hansen et al. 2013) with a 30 m resolution. Most of the deforestation has occurred in the lowland miombo woodlands in the hinterland of Dar Es Salaam upto Morogoro. Source: Hansen/UMD/Google/USGS/NASA

Slope Analysis: identifying areas with steep terrain that are prone to soil erosion



Elevation of Mkindo catchment, Ngurus.



Slope map for same area. Red areas indicate steepest slopes (angles > 45 degrees

Steep slopes in a catchment are the most vulnerable parts of the catchment to soil erosion; especially following the loss of forest cover. Soil erosion is one of the most serious problems affecting water quality (turbidity loss of aquatic ecosystems due to sedimentation of river bottom) as well as increased flooding risk due to decreased channel depth. In addition, the loss of soil from watersheds is a valuable loss. Usually, the steepest slopes are the last to be cleared for farming on account of the lack of adequate soil for cultivation, difficulty of access and rapid instantaneous drainage. Most of the steeper slopes in the Ngurus are thus still forested, and in the upper reaches of the valley, have reserved forest protected status. However, the pressures of a growing population are resulting in the extension of farming right up to the borders of reserve forests.

Terrain analysis can create slope maps (right) which can be used to identify the areas with steep slopes. Such maps target specific areas for assessing erosion potential, followed by strategies for the protection of forest cover and terracing / soil conservation measures in locations where forest has been cleared for agriculture/ pasture. Maps are created with slope value for each pixel (as opposed to elevation in the case of an elevation map). In addition, the analysis creates a tif image of the entire catchment that can be loaded in ArcMAP and zoomed in to obtain geospatial coordinates (lat long or UTM) of specific areas with steep slopes around a village that can then be used by field personnel equipped with a hand-held GPS to locate these areas in the field.

7.4 Adaptation to uncertain water supply and increasing demand

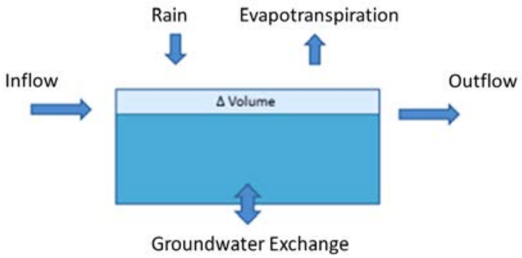
In the Wami/Ruvu Basin, communities have been adapting to changing environments and socioeconomic factors. Today, those factors are further complicated by global climate change and urban resource needs. Water being central to all life, the development and implementation of adaptation strategies needs the cooperation of all stakeholders (water users).

Focal areas for adaptation to climate change in the Wami/Ruvu Basin:

- Monitoring hydrology, creating basin water balance for water use permitting and pricing
- Training, community awareness generation and community water monitoring programs
- Increasing natural buffering capacity of watershed through forest & wetland protection and soil/water conservation
- Maintaining water storage, supply and control infrastructure
- Developing sector-wise plans, eg. agriculture, wastewater treatment and natural disaster response management with other agencies and stakeholders

Demonstrating rainfall measurement in a locally-made rain gauge (straight-sided water bottle with top cut and inverted to make a funnel) as part of a Community Water Monitoring Program being initiated in villages in the Mkindo river catchment, Wami Basin.

The plan is for village schools to keep daily records of rainfall in their area and analyze seasonal patterns, periods with no rain, periods with heavy rainfall, etc. In addition this data can be shared with the local catchment Water User Association and the Water Basin Office to provide a spatial picture of rainfall across the catchment. Such programs raise awareness in communities to assume greater involvement in managing local water resources, as well as can form the basis of an early flood warning system.



A water balance of a region (catchment, lake, basin, etc.) sums up the inputs and outputs of water to the region of interest over a period of time, such as one month.
The difference between inputs and outputs is then equated to the change in storage and error.
Calculating a water balance or budget enables estimation of the amount of water available for human consumption and the ecosystem. Hydrological data is required to be collected with adequate spatial representation.

Riparian vegetation cover

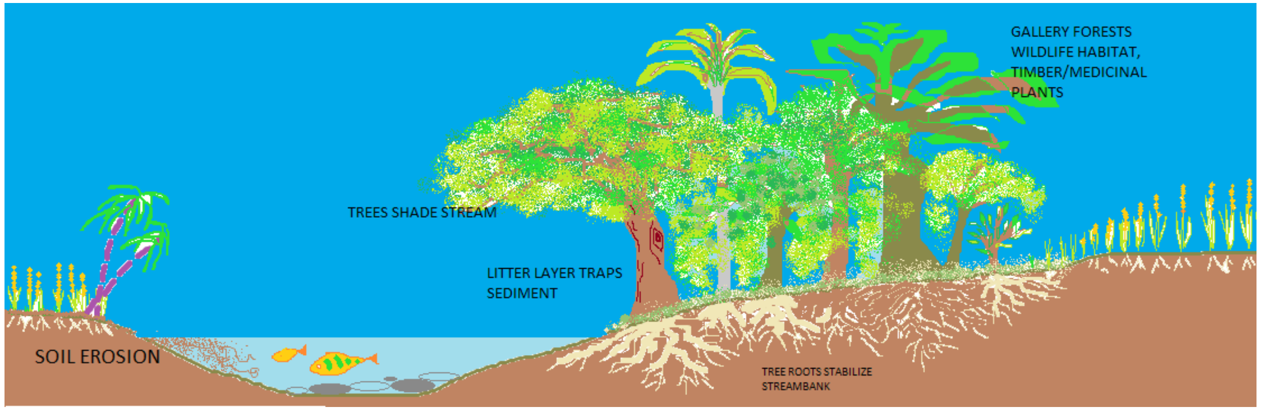
Woody vegetation along streambanks are intricately connected with the healthy functioning of aquatic ecosystems and water quality.

Riparian or gallery forests are very effective in trapping soil in surface runoff, thereby minimizing sedimentation of stream channels. Sedimentation decreases channel depth thereby increasing flood risk during high flow. Sedimentation of stream bottoms also wipes out habitat for aquatic macroinvertebrates (insect larvae) that play an important role in hastening organic litter degradation as well as form an important prey base for fish.

Forests also shade streams, keeping temperatures cool that then support higher levels of dissolved oxygen, important for fish and in-stream decomposition processes. In addition, trees provide food for fish and invertebrates. Gallery forests often are the only forests that remain on an agriculture-dominated landscape, and thereby provide habitat for wildlife, especially migratory birds.

This is the basis of Tanzania's regulations stressing no cultivation/development 60m from the riverbank. Successful implementation of riparian buffers requires awareness generation amongst local communities as to the significance of gallery forests on water quality and fisheries maintenance.

Trees and other vegetation occurring on both banks of a section of the Mkindo river



Schematic of a riparian vegetation buffer for a stream in Tanzania.

Riparian buffer corridors

Natural woody vegetation along streambanks (riparian buffers) provide the last defense to streams from nonpoint pollution originating from soil erosion and agrochemical in surface runoff in the watershed.

Because of the almost year-round availability of soil moisture in streambanks that are topographic lows on the landscape, gallery forests have their own unique ecosystem and species assemblages. This schematic illustrates the importance of connectivity these gallery forest habitats in addition to the value they provide in buffering streams from nonpoint pollution.

Information Resources for the Wami/Ruvu Basin

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