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IUCN WATER AND NATURE INITIATIVE

PANGANI BASIN WATER BOARD[1]

PANGANI RIVER BASIN FLOW ASSESSMENT

River Health Assessment Final Report

H. Dallas, J. King, C. Brown, G. Lugomela, J. Mbaga, E. Materu, A. Maggidi, B. L. Benno, L. T Kaaya, F. Mbago and S. Kamugisha

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ABBREVIATIONS

ABBREVIATION	MEANING
ASPT	Average Score Per Taxon
FA	Pangani River Basin Flow Assessment Initiative
ha	hectare
HEP	Hydro-electric power
IHAS	Invertebrate Habitat Assessment System
IHI	Index of Habitat Integrity
IUCN	World Conservation Union
m^3/s	cubic meters per second
masl	meters above sea level
mgl^{-1}	milligrams per litre
Mm^3	million cubic meters
mSm^{-1}	MilliSiemens per litre
MSL	Mean Sea Level
Mt	Mount
NTU	Nephelometric Turbidity Units
NYM	Nyumba ya Mungu
PBWO	Pangani Basin Water Office
ppt	parts per thousand
PRB	Pangani River Basin
R	Prefix for river sampling sites (Riv in Basin Delineation report)
SASS	South African Scoring System
TPC	Tanganyika Planting Company
μgl^{-1}	micrograms per litre

EXECUTIVE SUMMARY

This report forms part of the Pangani River Basin Flow Assessment Initiative. It is based on a health assessment of the river during the wet and dry seasons, together with existing PBWO water-quality data collected at key points along the river. Thirteen study sites (Figure E1) were selected to represent a range of zones (Mountain Stream; Upper Foothill; Lower Foothill; Mature Lower River and Rejuvenated Bedrock Cascade).

The methods used for the assessment are based on those developed in the River Health Programme of the National Aquatic Ecosystem Health Biomonitoring Programme of South Africa. The method involves the collection of information necessary to characterise a site, to provide an indication of catchment condition and land-use, together with relevant abiotic (water quantity and quality) and biotic (invertebrates, fish, riparian vegetation) information. Each of these biotic components provides information of the health on the instream or riparian zone of the river. A field manual and associated datasheets have been compiled for use in the IUCN-Pangani Basin River Health assessment.

The results section provides a description of the characteristics of each site, including a description of channel classification and stream dimensions, together with a photographic record for each site during the wet and dry seasons. In terms of water quantity, discharge were generally higher at sites in the wet season compared to the dry season, with the exception of two lower foothill sites (R8 and R9), both below NYM dam. Sites R2, on the Kikuletwa River, and R7, on the Muraini River, dried up during the dry season; the latter due to the seasonal nature of the river. The site on the mature Lower River (R11) had highly variable flow within a 24-hour period in the dry season due to storage and releases from the Pangani Falls Hydropower station.

Water quality varied from site to site - in response to both position in the catchment, i.e. upper versus lower reaches, and to changing water quality due to anthropogenic activities. Turbidity was higher than expected in the Upper Foothill Zone of the Kikuletwa River (R2), and PBWO monitoring data indicated that levels were also high in the Themi and Kware Rivers. The pH values showed no or very slight variation among the sites and were mostly close to neutral. They were within the range of 6.61 to 8.42 in the wet season and generally increased slightly to a range of 7.14 to 8.93 in the dry season. Conductivity was lowest in the Mountain Stream and Upper Foothill zones (6.7 to 14.0 mSm^{-1}), except for R2 in the wet season, where it is higher than expected (23.9 mSm^{-1}). Conductivity increased markedly at two sites (R3 - Kikuletwa River and R12 - Mkomazi River) from wet to dry seasons. PBWO monitoring data also indicate that high conductivity was measured on the Kware and Kikuletwa Rivers, as well as the Themi and Maji ya Chai Rivers downstream of the Arusha-Moshi road. Dissolved oxygen (DO) concentrations ranged from 5.5 - 8.9 mgl^{-1} in the wet season and were generally lower in the dry season (5.0 - 7.8 mgl^{-1}). One site R6 had extremely low levels of dissolved oxygen (< 0.6 mgl^{-1}). In terms of nutrients, the concentration of total nitrogen (TN) was elevated at a two sites in the wet season, while total phosphorous (TP) was low at most sites. This changed in the dry season with TP increasing at most sites resulting in a shift in trophic status from the wet to dry seasons. Algae were present at more sites in the dry season. The concentration of bicarbonates increased below NYM (R8) and from wet to dry season at R3 - Kikuletwa River. Organic enrichment (Biological Oxygen Demand and faecal coliforms), as determined from the PBWO water quality monitoring data, was elevated at sites near Arusha and Moshi. High BOD values were recorded on the Themi River downstream of Arusha and high faecal coliform counts were observed on the Kikuletwa, Themi, Tenguru, Ngarenaro and Njoro Rivers and Lake Jipe at Makuyuni.

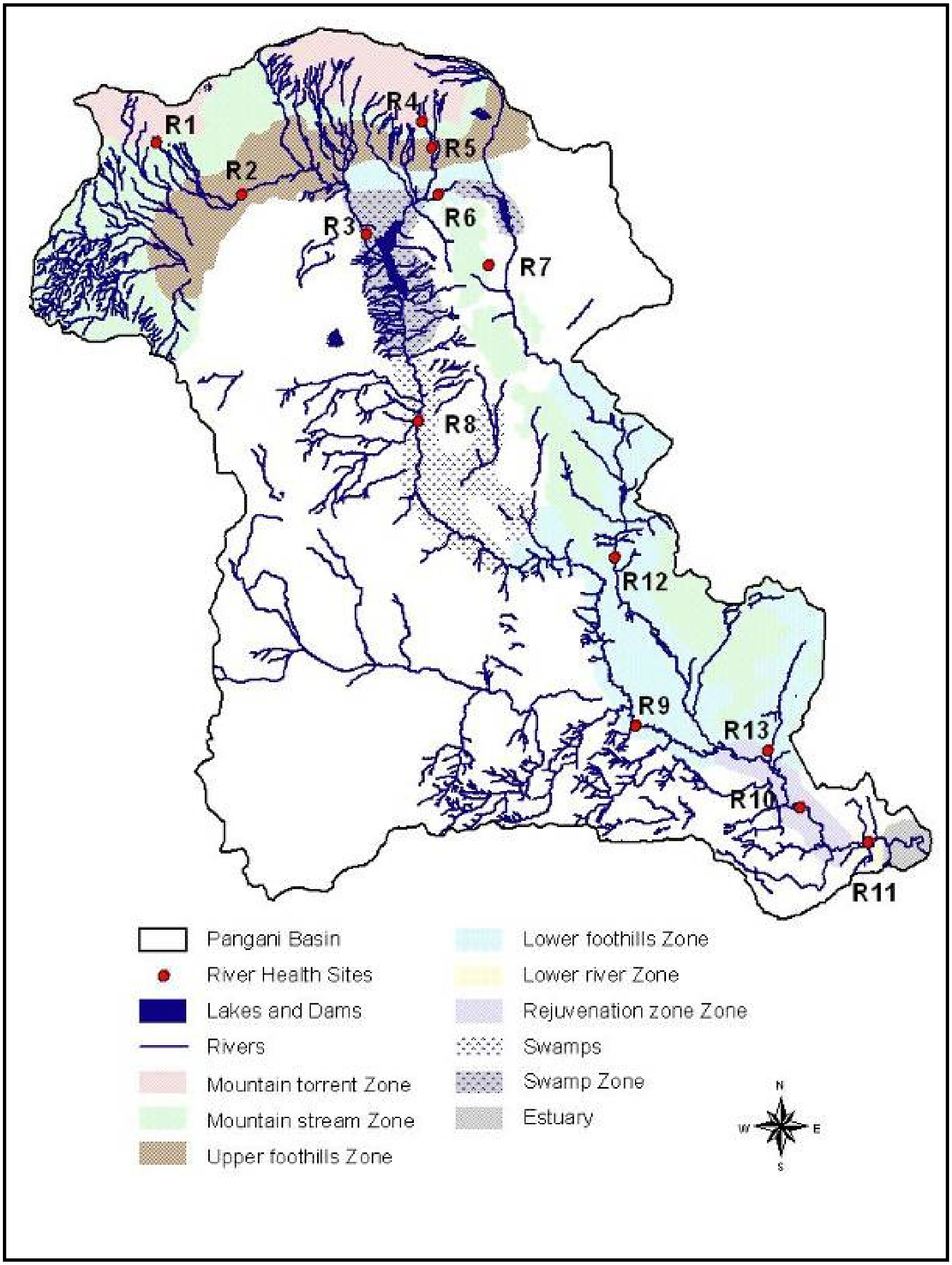

Figure E1.1 Sites within the Pangani River Basin assessed for river health. Zones are indicated.

Details of the abiotic and biotic components, i.e. invertebrates, fish and riparian vegetation, are provided. Briefly, a total of 54 invertebrate taxa (mostly family-level), 23 fish species and 233 plant species were recorded during this survey. Following the analysis of the data collected for each of the components assessed, a discussion was held to determine the status of each of the components using common categories to indicate the level of modification from an expected natural or baseline condition (A - Natural, unmodified system; B - Largely natural, slightly modified system; C - Moderately modified system; D - Largely modified system; E* - Only for IHI - Seriously modified system; and F* - Only for IHI - Critically modified system). Key issues are highlighted and relevant information summarized for each site assessed during the river health survey.

R1 - Nduruma River (Zone: Mountain Stream)

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
C	B	B	F	B	B	C

- **Discharge**: <40% of water was abstracted in the wet season and >80% in the dry season. The dry season flows were reduced and the duration of these dry season flows was extended, with less water in the river generally.
- **Water quality:** DO concentrations decreased and TP increased in the dry season. Trophic status shifted from mesotrophic to eutrophic in the dry season.
- **IHI Instream**: Moderately modified because of water abstraction and flow modification.
- **IHI Riparian:** Critically modified because of the decrease of indigenous vegetation from the riparian zone, exotic vegetation encroachment and bank erosion.
- **Invertebrates**: There was a reasonable diversity of invertebrates in both the wet and dry seasons, with all three biotopes present. A total of 23 taxa were recorded, including four families of mayflies, as well as dragonflies, caddisflies, beetles and flies.
- **Fish**: Habitat was limited to fast flowing, shallow areas and deeper runs. One fish species was caught, *Garra dembeensis*, which is adapted to living in fast flowing streams.
- **Riparian Vegetation**: The riparian width was 30m on the right hand bank and 5m on the left hand bank. Trees, shrubs, sedges and grasses were represented. Encroachment by exotic vegetation was widespread and smaller areas were invaded by terrestrial plants.

R2 - Kikuletwa River (Zone: Upper Foothill)

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
D	D	D	F	D	D	D

- **Discharge**: The river at this site was no longer perennial and in the dry season it dries up. Floods were smaller but the number of floods has remained the same when compared to historical events.
- **Water quality:** High turbidity value for an Upper Foothill site - most likely due to removal of riparian vegetation and extensive livestock farming.
- **IHI Instream**: Largely modified because of water abstraction and flow modification.
- **IHI Riparian:** Critically modified because of the decrease of indigenous vegetation from the riparian zone, exotic vegetation encroachment and bank erosion.

- **Invertebrates**: This site showed indications of a loss of invertebrates, with lower SASS5 Scores in comparison to the other Upper Foothill sites. A total of 15 taxa were recorded in the wet season - the site was dry during the dry season.
- **Fish**: In the wet season, habitat was limited to fast deep areas, with some overhanging vegetation, undercut banks, gravel substrate and water column. One species was recorded, *Clarius gariepinus*, although fisherman indicate that two additional species of *Tilapia* also occur.
- **Riparian Vegetation**: The riparian zone at the sampling point was almost bare due to removal of riparian vegetation and livestock watering. Downstream of the site, the riparian width was 40m on the right hand bank and 30 on the left hand bank. Trees, shrubs, sedges and grasses were represented. Encroachment by exotic vegetation and terrestrial plants was limited.

R3 - Kikuletwa River (Zone: Lower Foothill)

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
C/D	B/C	D	E	B	C	C

- **Discharge**: The river at this site had substantially less water during the dry season compared to the wet season. The floods have not changed significantly in terms of size or frequency. Dry season flows were extended beyond the expected dry season and the river was perennial because it is sustained by the Chemka Springs upstream.
- **Water quality:** Conductivity, carbonates/bicarbonates, magnesium and TP increased in the dry season.
- **IHI Instream**: Largely modified because of water abstraction, flow modification and water quality.
- **IHI Riparian:** Seriously modified because of the decrease of indigenous vegetation from the riparian zone and bank erosion.
- **Invertebrates**: The number of taxa and SASS Scores decreased from wet to dry season. A total of 25 taxa were recorded. The fauna included worms, crabs, water-mites, mayflies, dragon- and damselflies, bugs, caddisflies, beetles and flies. Of note was the only record of the caddisfly family, Ecnomidae, in the wet-season survey. Lack of vegetation in the dry season resulted in fewer taxa being recorded.
- **Fish**: In the wet season, habitat was limited to fast, deep areas and in the dry season to fast and slow, shallow areas. There was overhanging vegetation, undercut banks, gravel and rocky substrate and water column. Five species were recorded, although fisherman indicated that two additional species were present.
- **Riparian Vegetation**: The riparian zone was divided into riparian and floodplain, with widths 50m, 50m on the right hand bank and 40m, 90m on the left hand bank for riparian and floodplain respectively. Trees, shrubs, reeds, sedges and grasses were represented. There was no encroachment by exotic vegetation, reeds or terrestrial plants.

R4 - Ona River (Zone: Mountain Stream)

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
B/C	A/B	B	C	A	A/B	B

- **Discharge**: The river at this site was perennial, although flows were lower in the dry season compared to the wet season. There was abstraction for local farming.
- **Water quality:** There were no apparent changes from wet to dry season.

- **IHI Instream**: Largely natural with few modifications - water abstraction.
- **IHI Riparian:** Moderately modified because of exotic vegetation encroachment.
- **Invertebrates**: This site only had stones biotope for sampling - nonetheless, it had the highest SASS5 Score for this biotope (in both seasons) compared to all other sites assessed. Flatworms, crabs and water-mites, four families of mayflies, as well as dragonflies, bugs, caddisflies, beetles (including Elmidae and Psephenidae) and flies. A total of 16 taxa were recorded.
- **Fish**: Habitat was largely limited to fast, deep and fast, shallow areas. There were large amounts of overhanging vegetation (trees), few undercut banks, rocky substrate and water column. Two species were recorded, although fisherman indicated that an additional species was present.
- **Riparian Vegetation**: The riparian width was 70m on the right hand bank and 80m on the left hand bank. Trees, shrubs and grasses were represented. There was no encroachment by exotic vegetation.

R5 - Himo River (Zone: Upper Foothill)

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
C	C	D	C	C	C	C

- **Discharge**: The river at this site was perennial, although flows were substantially lower in the dry season compared to the wet season and the dry period was extended beyond the expected dry season. There was water abstraction (Himo town nearby).
- **Water quality:** Temperature increased with lower flows and silt was deposited on stones. Sources of water quality impairment result from localized use of the river by people from the town of Himo, e.g. washing cars, clothes, bathing. Bacterial contamination (faecal coliforms) was likely to be a problem - this may impact upon human health.
- **IHI Instream**: Moderately modified because of water abstraction, flow modifications and water quality. Gravel, cobble and sand were extracted upstream.
- **IHI Riparian:** Moderately modified because of exotic vegetation encroachment and bank erosion.
- **Invertebrates**: There was drop in the number of taxa and scores from wet to dry season. Stones were covered in silt in the dry season and the quality of the stones and vegetation biotope was decreased. The total number of taxa recorded was 23. The limpet, Ancylidae, was only recorded at this site (dry season).
- **Fish**: Habitat was largely limited to fast, deep in the wet season, and slow, deep and slow, shallow in the dry season. There was overhanging vegetation, undercut banks, rocky and sandy substrate and water column. Three species of fish were recorded.
- **Riparian Vegetation**: The impact on the riparian vegetation was localized. Downstream of the site the riparian width was 10m on the right hand bank and 10m on the left hand bank. Trees and shrubs dominated with a few sedges and grasses present. There was very limited encroachment by exotic vegetation.

R6 - Ruvu River (Zone: Lower Foothill)

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
B/C	D	D	D	D	D	C

- **Discharge**: The river at this site was perennial, although flows were lower in the dry season compared to the wet season, and the dry period was extended beyond the expected dry season. Annual flooding occurs and the low flows were sustained by outflow from Lake Jipe. There was a wetland upstream of the site although information on this was limited. Lake Jipe has experienced a decline in water levels over the last decade.

- **Water quality:** Critically low dissolved oxygen levels during the wet and dry seasons - extensive decaying material, low-gradient river downstream of Lake Jipe. TP increased during the dry season. Aquatic macrophytes were recorded in the dry season, indicating that TN was limited (*Azolla pinnata* has nitrogen fixing bacteria associated with it).
- **IHI Instream**: Largely modified because of water quality impairment (DO) and exotic macrophytes).
- **IHI Riparian:** Largely modified because of a decrease in indigenous vegetation and bank erosion.
- **Invertebrates**: Biotopes were limited to vegetation and mud in the wet season with gravel/cobble also available in the dry season. The scores dropped from wet to dry season, although two more taxa were recorded in the dry season. Total number of taxa was 16. Dominant invertebrates were air breathers (e.g. several bug taxa) and those adapted to living in waters with low dissolved oxygen e.g. *Chironomus* spp. and oligochaetes.
- **Fish**: Habitat was largely limited to fast, deep in the wet season, and slow, deep in the dry season. There was overhanging vegetation (sedges and trees), few undercut banks, macrophytes; rock, gravel and sand substrate and water column. Five species were recorded in the wet season - possibly migrating upstream to the swamp area for spawning. Two additional species were recorded in the dry season. Fish were observed gulping for air, indicating stress resulting from low DO concentrations.
- **Riparian Vegetation**: The riparian width was 10m on the right hand bank and 18m on the left hand bank. Trees, shrubs, reeds, sedges and grasses were represented. There was very limited encroachment by exotic vegetation.

R7 - Muraini (Mvuleni) River (Zone: Upper Foothill)

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
D	B/C	C	C	B/C	-	A

- **Discharge**: The river at this site was seasonal and it naturally ceases to flow in the dry season. Water abstraction in the wet season was estimated at >60%. It was likely that the dry season was extended beyond the expected dry season because of the abstraction during the wet season. No information was available on floods.
- **Water quality:** Turbidity and TSS were higher than expected for an Upper Foothill site - this may be a consequence of the rain that preceded the assessment.
- **IHI Instream**: Moderately modified because of water abstraction, flow modifications and water quality.
- **IHI Riparian:** Moderately modified because of bank erosion.
- **Invertebrates**: The stones biotope was limited to a small, shallow, cobble riffle. No marginal vegetation was available for sampling. A total of 13 taxa were recorded. It was one of two sites in the survey where butterfly larvae, Crambiidae, were recorded.
- **Fish**: Habitat was limited to slow, shallow pool areas. There was overhanging vegetation, undercut banks in the pool area and gravel substrate. Little cover was provided by the water column. No fish were caught, although they were known to be found downstream in the rainy season.
- **Riparian Vegetation**: The riparian width was 150m on the right hand bank and 200m on the left hand bank. Trees, shrubs and grasses were represented. There was very limited encroachment by exotic vegetation. The riparian vegetation has a

closed canopy with minimal undergrowth herbaceous plants. The dominant plants were the fig trees (*Ficus* ssp.) which are adapted to surviving in dry areas due to their ability to reserve/store water.

R8 - Pangani River (Zone: Lower Foothill)

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
D	C	C	C	C	A/B	B

- **Discharge**: Flow was highly regulated by NYM dam and there was no significant inflow between the dam and the site. Floods were held back at the dam, high flows were irregular and flows were constant. Dry season base flows were higher than wet season base flows. Flooding of Kirua swamps no longer occurs. Depth of the river at this site has increased due to trapping of sediment by the dam.
- **Water quality:** TP increased in the dry season - causing a shift in trophic status from mesotrophic to eutrophic. The NYM dam upstream was located on calcareous soils - very high levels of carbonates and bicarbonates were released from the dam. The elevated levels continue into the Mature Lower River.
- **IHI Instream**: Moderately modified because of water abstraction, flow modifications and water quality.
- **IHI Riparian:** Moderately modified because of decrease of indigenous vegetation and bank erosion.
- **Invertebrates**: Only marginal vegetation was available for sampling. Fifteen taxa were recorded, including mayflies, damselflies, bugs, caddisflies, beetles and flies.
- **Fish**: Habitat was limited to fast, deep areas. There was overhanging vegetation, emergent macrophytes, gravel/sand/mud substrate and water column. Ten species of fish were recorded. Migratory fish species were recorded, but their availability and distribution may be affected by the fishing weir upstream.
- **Riparian Vegetation**: The riparian width was 10m on the right hand bank and 15m on the left hand bank. Trees, shrubs, reeds, sedges and grasses were all well represented. There was no encroachment by exotic vegetation.

R9 - Pangani River (Zone: Lower Foothill)

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
D	C	C	D	B	B	B

- **Discharge**: Flow was regulated by NYM dam and there was no significant inflow between the dam and the site. Floods were held back at the dam, high flows were irregular and flows were constant. Dry season base flows were higher than wet season base flows.
- **Water quality:** Higher nitrogen concentrations and chlorophyll *a* levels in the wet season indicated that the system was modified in terms of water quality. TP increased in the dry season causing a shift in trophic status from mesotrophic to eutrophic. Upstream of the site there was extensive sisal plantations, cattle ranches and localized agriculture in the riparian zone.
- **IHI Instream**: Moderately modified because of water abstraction, flow modifications and water quality.
- **IHI Riparian:** Largely modified because of decrease of indigenous vegetation.
- **Invertebrates**: There was decrease in number of taxa and SASS5 Score from wet to dry season. This may have been a reflection of the difficultly in sampling the biotopes under the higher dry season flows. The total number of taxa recorded was 17. The fauna included crabs, water-mites, mayflies, butterfly larvae, dragon-

and damselflies, bugs, caddisflies, beetles, flies and snails. Of note were the five different types of cased-caddisfly in the family Leptoceridae in the wet season.

- **Fish**: Habitat included fast, deep and fast, shallow (bedrock rapids) areas. There was overhanging vegetation, rocky and sandy substrate and water column. Four species of fish were recorded. There was a fishing weir across the river and discussions with local fishermen indicated that seven species have been caught at this site.
- **Riparian Vegetation**: The riparian width was 10m on the right hand bank and 5m on the left hand bank. Trees, shrubs, reeds, sedges and grasses were all represented. There was no encroachment by exotic vegetation.

R10 - Pangani River (Zone: Rejuvenated Bedrock Cascade)

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
D	D	D	E	D	C/D	D

- **Discharge**: Flow was regulated by NYM dam and there was an additional pool (head pond) for storing water before entering the Hale Hydropower station. There were several rivers joining the Pangani River upstream of this site, which contributed to inflows. Floods seem to have the normal pattern. In the dry seasons, the river below the HEP sometimes dries out due to the entire river water being abstracted to generate HEP.
- **Water quality:** Conductivity, nitrites and TP increased in the dry season. The system shifted from mesotrophic to hypertrophic. DO decreased especially in the slower flowing areas of the river. Bacterial contamination (faecal coliforms) may impact upon human health at this site. Rubbish dumping occurred within the riparian zone.
- **IHI Instream**: Largely modified because of water abstraction, flow modifications, water quality, bank modifications and presence of solid wastes.
- **IHI Riparian:** Seriously modified because of decrease of indigenous vegetation, exotic vegetation encroachment and bank erosion.
- **Invertebrates**: More taxa were recorded in the dry season (19 taxa) compared to the wet season (13 taxa), although most of them were ones that were able to tolerate reduced water quality (e.g. Oligochaete, Corixidae, Notonectidae). Three taxa were recorded in the stones in the wet season, including leeches (Hirudinea), while 12 taxa were recorded in stones in the dry season (greater accessibility due to the lower water levels). The total number of taxa recorded was 22.
- **Fish**: Habitat included fast, deep and fast, shallow (bedrock rapids) areas in the wet season, but changed to slow, shallow areas in the dry season. There was sparse undercut banks, rocky substrate and water column (decrease from wet to dry season). Ten species of fish were recorded in the wet season, but no fish were recorded in the dry season. This may be a reflection of the reduction in water quality and quantity (backwater habitat not available in the dry season), although problems with the electroshocker may also have contributed to this.
- **Riparian Vegetation**: The riparian width was 5m on the right hand bank and 5m on the left hand bank. Trees, shrubs, sedges and grasses were represented. There was limited encroachment by exotic vegetation. The riparian vegetation was severely exploited and the impact from rural development was high.

R11 - Pangani River (Zone: Mature Lowland River)

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
D	C	D	E	C	C	B

- **Discharge**: Flow was regulated by NYM dam and there were two additional pools (head ponds) for storing water before entering the Pangani Falls Hydropower station. There were several rivers joining the Pangani River upstream of this site, which contributed to inflows. Flows below the intake depend on releases from the HEP and were intermittent in the dry season. The river below dries up for approximately 8 hours in every 24 hours. The natural Pangani River sometimes dries out in the dry season due to abstraction for HP.
- **Water quality:** Turbidity was elevated below the HEP station due to releases from the station. Nitrite increased in the dry season. The sub-site R11A, which was on the natural river above the confluence with the outflow, had higher TP in the dry season, which caused a shift in trophic status from mesotrophic to hypertrophic.
- **IHI Instream**: Largely modified because of water abstraction, flow modifications and water quality.
- **IHI Riparian:** Seriously modified because of decrease of indigenous vegetation and exotic vegetation encroachment.
- **Invertebrates**: Three taxa were recorded in the wet season, including the shrimp (Atyidae). A total of seven taxa were recorded. More taxa (6) were recorded in the dry season, although these included highly tolerant worms, Oligochaete, air-breathing Corixidae, Notonectidae and Dytiscidae. Prawns were recorded at R11A, on the natural river upstream of the confluence with outflow.
- **Fish**: Habitat included fast, deep areas in the wet season. In the dry season, habitat was severely compromised through the drying up of the river. There was overhanging vegetation (trees), macrophytes, substrate (gravel) and water column in wet season. Seven species of fish were recorded in the wet season, but no fish were recorded in the dry season. Some of these were estuarine species. Site R11A also had bedrock and overhanging vegetation was shrubs. Three species of fish were caught at R11A in the dry season, including an eel, which is a migratory species that matures in the river and then migrates to the ocean to spawn.
- **Riparian Vegetation**: The riparian width was 70m on the right hand bank and 5m on the left hand bank. Trees, shrubs, sedges and grasses were represented. There was limited encroachment by exotic vegetation.

R12 - Mkomazi River (Zone: Lower Foothill)

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
D	C/D	D	F	C/D	C/D	D

- **Discharge**: Dry season flows were extended beyond the expected dry season and the river may dry up at the end of the dry season. Floods occur but the size has been reduced due to the presence of the Kalimawe Dam upstream. The floodplain was not inundated to extent that it used to be.
- **Water quality:** Conductivity and sulphate concentration were high in the wet and dry season. Conductivity, sulphate and TP increased in the dry season and trophic status changed from mesotrophic to eutrophic. DO decreased in the dry season. There was extensive agriculture upstream of the site including sisal production and maize and the entire floodplain was cultivated.
- **IHI Instream**: Largely modified because of water abstraction, flow modifications and water quality.
- **IHI Riparian:** Critically modified because of decrease of indigenous vegetation. Cultivation of crops occurs within the floodplain.
- **Invertebrates**: Vegetation and mud were available for sampling. A total of 17 taxa were recorded: nine in the wet season and 14 in the dry season, although most of them were relatively tolerant ones. Taxa including worms, mayflies, damsel- and dragonflies, caddisflies, beetles, flies and snails.

- **Fish**: Habitat was largely slow, shallow areas. There was overhanging vegetation (reeds, shrubs), gravel and sand substrate and water column was limited. Overhanging vegetation provides important habitat at this site. Seven species of fish were recorded: six in the wet and one in the dry season. *Clarius gariepinus* (air-breathers) were present - they were tolerant of harsh conditions such as extremely low flows (and drying up).
- **Riparian Vegetation**: The riparian width was 45m on the right hand bank and 105m on the left hand bank. Reeds and sedges dominated. There was extensive encroachment by exotic vegetation, in addition to some terrestrial plants.

R13 - Luengera River (Zone: Lower Foothill)

Discharge	Water Quality	IHI In stream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
C	C	C	C	C/D	C	B

- **Discharge**: Dry season flows were extended beyond the expected dry season (due to water abstraction for agriculture) and the river dried up in 2004. Floods occur but the size has been reduced in the past 15 years. There was an extensive floodplain area that still appears to flood annually - wetlands were filled with water in the adjacent floodplain.
- **Water quality:** TN was high in the wet season, possibly as a result of agriculture (sisal, maize, rice) in the surrounding area. TP increased in the dry season and trophic status changed from mesotrophic to eutrophic.
- **IHI Instream**: Moderately modified because of water abstraction, flow modifications and water quality.
- **IHI Riparian:** Moderately modified because of decrease of indigenous vegetation.
- **Invertebrates**: This site had a relatively high SASS5 Score and ASPT in the wet season compared to other Lower Foothill sites that only had vegetation and mud for sampling. A total of 18 taxa were recorded: 13 in the wet season, including crabs, mayflies, damsel- and dragonflies, bugs, caddisflies, beetles and snails. Fewer taxa were recorded in the dry season and scores were lower. Leeches were recorded in the dry season.
- **Fish**: Habitat was largely slow, shallow areas. There was overhanging vegetation (reeds and trees), mud substrate and water column. Five species of fish were recorded. Local fishermen indicated that an additional three species were recorded in this site.
- **Riparian Vegetation**: The riparian zone was divided into riparian and floodplain, with widths 2, 120m on the right hand bank and 5, 100 on the left hand bank for riparian and floodplain respectively. Trees, shrubs, reeds, sedges and grasses were represented. There was no encroachment by exotic vegetation, reeds or terrestrial plants.

In summary, river health varied from site to site, in response to both natural changes within the catchment and anthropogenic impacts that have modified the water quantity and/or quality of the river system. Whilst this study has focused on an assessment of river health, much of the data gathered can be of use in an environmental flow assessment. To this end, focused questions aimed at providing additional information on environmental flows, have been addressed and summarized in an appendix.

In addition to the results presented in this report, team members responsible for the river health survey have learnt a great deal during this exercise. They should be well equipped to undertake similar surveys within Tanzania, thereby enhancing the understanding of river systems in the country and allowing for management based on river health knowledge that includes abiotic and biotic components.

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1 INTRODUCTION

1.1 Background

The Pangani River Basin Flow Assessment is an IUCN-Pangani Basin Water Office (PBWO) initiative that brings together a Flow Assessment Group selected from within Tanzania, consisting of specialists in a range of river-related, water-allocation and policy-making disciplines. These specialists are working together with advisors from South Africa to develop an understanding of the hydrology of the Pangani River Basin, the nature and functioning of the river system and the links between the river and socio-economic value of its resources. This report addresses one component of Task 3 of the Pangani River Basin Flow Assessment Initiative: **a health assessment of the river during the wet and dry seasons**. The Task was accomplished by undertaking a river health assessment at 13 sites along the major tributaries and the main stem of the Pangani River in two seasons: wet and dry. This, together with an evaluation of existing water-quality data collected at key points along the river, will form the basis of the report on the health of the river. The river health assessment serves to establish a baseline for monitoring and facilitates the identification of areas of concern, whilst providing a base for the development of knowledge for the river and basin.

1.2 Layout of this report

This report provides information on the methods used for each component of the river health assessment, presents the results from the wet and dry seasons per abiotic and biotic components, discusses overall river health per site and provides information on the links to environmental flows where possible.

2 METHODS

2.1 River zonation and site selection

The study sites for the river health assessment were selected during a desktop exercise aimed a delineating the basin into relatively homogeneous zones and sub-zones (= reaches) (PWBO/IUCN 2006). Thirteen study sites were selected from a total of 28 individual river reaches (Figure 2.1, Table 2.1). These sites were sampled between 12 and 18 June 2006, representing the wet season, and 26 September to 1 October, representing the dry season. Criteria to consider when selecting sites for river health assessments are provided in Appendix A. A site is the area immediately where the sampling was conducted (normally < 100m in length), while a reach represents a relatively homogeneous zone in terms of biophysical characteristics. Geomorphological zones are based on Rowntree and Wadeson's (2000) geomorphological zonation of river channels (Table 2.2).

The reaches that were excluded during basin delineation and the reasons for their exclusion are given below:

- Nyumba ya Mungu Dam - a man-made structure for which there is considerably more ecological information available than for the rivers;
- Lake Jipe - which was the subject of an independent and detailed study in 2004/2005;
- four Mountain Torrent Zones - access to these areas is difficult and there are no hydrological data for the zones;
- one of the zones (LF3) in the lower Pangani River between Nyumba ya Mungu Dam and the rejuvenation zone at the town of Korogwe - subjected to similar anthropogenic impacts to the other zone (LF4),
- the Tengeru and Sanya Rivers (a total of four river reaches, excluding the Mountain Torrent Zones excluded above) - river health data to be extrapolated from the Kikuletwa River;
- one of the two reaches on the Muraini River - there are no hydrological data for this river, and sampling of only one site should provide sufficient information on health (in the context of the coarse resolution of the study);

- the rejuvenation zones on the Kikuletwa and Ruvu Rivers - access to these areas is difficult and social utilisation of these reaches appears to be less than for the other reaches;
- the Mountain Stream zones in the Pare and Usambara Mountains - these are short systems that are difficult to access;
- Shambalai Swamp - there are no hydrological data for this swamp.

Table 2.1 Study sites within the Pangani River Basin assessed for river health. River sub-zone codes from the harmonized river sub-zones (Table 3.9 of the Basin Delineation report) are given in brackets.

Site No.	River system	River name at reach	Coordinates (WGS 84)	Location Description	River Zone (after ground-truthing)
R1 (MS1)	Kikuletwa R.	Nduruma R.	S03° 22.540' E36° 45.064'	U/S of Nduruma chini	Mountain Stream
R2 (UF1)		Kikuletwa R.	S03° 33.469' E36° 57.993'	U/S Wahoga chini (gauging station)	Upper Foothill
R3 (SW1)		Kikuletwa R.	S03° 38.564' E37° 21.235'	Upstream Nyumba ya Mungu	Lower Foothill, in Floodplain/Swamp
R4 (MS5)	Ruvu R.	Ona R.	S03° 18.861' E37° 30.925'	Samangai - Kimatoloni bridge	Mountain Stream
R5 (UF4)		Himo R.	S03° 23.448' E37° 32.611'	At Himo town, upper bridge (gauging station)	Upper Foothill
R6 (LF1)		Ruvu R.	S03° 31.732' E37° 33.759'	At Kifaru, upstream of the bridge	Lower Foothill
R7 (LF2)	Muraini R.	Muraini R. (Mvuleni R.)	S03° 43.794' E37° 42.472'	Upstream Jipe (at bridge)	Upper Foothill
R8 (FP)	Pangani R.	Pangani R.	S04° 10.920' E37° 30.186'	Kirua swamp	Lower Foothill, in Floodplain/Swamp
R9 (LF4)		Pangani R.	S05° 03.756' E38° 07.868'	Mkalamo village (at the bridge)	Lower Foothill
R10 (RBC)		Pangani R.	S05° 17.910' E38° 36.271'	Mwakinyumbi (Hale town downstream)	Rejuvenated Bedrock Cascade
R11(MLR)		Pangani R.	S05° 21.850' E38° 14.175'	Jambe village	Mature Lower River
R11A*		Pangani R.	S05° 21.689' E38° 40.156'	Jambe village	Lower Foothill / Rejuvenated Bedrock Cascade
R12 (LF5)	Mkomazi R.	Mkomazi R.	S04° 34.541' E38° 04.107'	Downstream Kalimawe dam (at Bendera)	Lower Foothill
R13 (LF6)	Luengera R.	Luengera R.	S05° 08.083' E38° 30.610'	At Kwamndolwa, old Korogwe	Lower Foothill

*Additional sub-site added during wet-season river health assessment

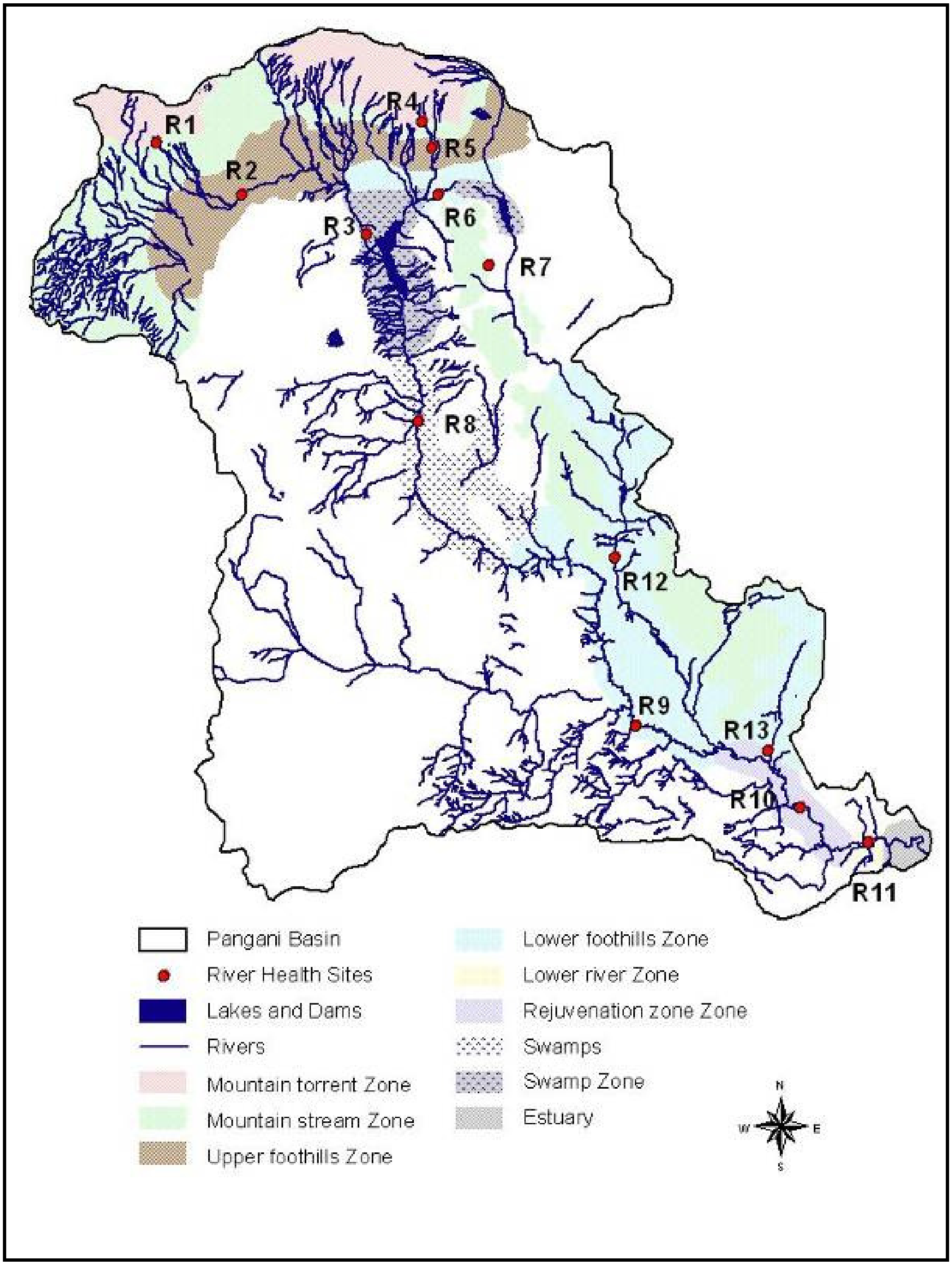


Figure 2.1 Sites within the Pangani River Basin assessed for river health. Zones are indicated.

Table 2.2 Geomorphological zonation (river sub-zones) of river channels (after Rowntree and Wadeson 2000).

Longitudinal Zone	Characteristic Gradient	Diagnostic Channel Characteristics
A. Zonation associated with a 'normal' profile		
Source zone	not specified	Low gradient, upland plateau or upland basin able to store water. Spongy or peaty hydromorphic soils.
Mountain headwater stream	> 0.1	A very steep gradient stream dominated by vertical flow over bedrock with waterfalls and plunge pools. Normally first or second order. Reach types include bedrock fall and cascades.
Mountain stream	0.04 - 0.99	Steep gradient stream dominated by bedrock and boulders, locally cobble or coarse gravels in pools. Reach types include cascades, bedrock fall, step-pool, plane bed. Approximate equal distribution of 'vertical' and 'horizontal' flow components.
Transitional	0.02 – 0.039	Moderately steep stream dominated by bedrock or boulder. Reach types include plain-bed, pool-rapid or pool riffle. Confined or semi-confined valley floor with limited flood plain development.
Upper foothills	0.005 - 0.019	Moderately steep, cobble-bed or mixed bedrock-cobble bed channel, with plane bed, pool-riffle or pool-rapid reach types. Length of pools and riffles/rapids similar. Narrow floodplain of sand, gravel or cobble often present.
Lower foothills	0.001 - 0.005	Lower gradient mixed bed alluvial channel with sand and gravel dominating the bed, locally may be bedrock controlled. Reach types typically include pool- riffle or pool-rapid, sand bars common in pools. Pools of significantly greater extent than rapids or riffles. Floodplain often present.
Lowland river	0.0001- 0.001	Low gradient alluvial sand bed channel, typically regime reach type. Often confined, but fully developed meandering pattern within a distinct floodplain develops in unconfined reaches where there is an increase in silt content in bed or banks.
B. Additional zones associated with a rejuvenated profile		
Rejuvenated bedrock fall / cascades	> 0.02	Moderate to steep gradient, often confined channel (gorge) resulting from uplift in the middle to lower reaches of the long profile, limited lateral development of alluvial features, reach types include bedrock fall, cascades and pool-rapid.
Rejuvenated foothills	0.001 - 0.02	Steepened section within middle reaches of the river caused by uplift, often within or downstream of gorge; characteristics similar to foothills (gravel/cobble bed rivers with pool-riffle/ pool-rapid morphology) but of a higher order. A compound channel is often present with an active channel contained within a macro channel activated only during infrequent flood events. A floodplain may be present between the active and macro-channel.
Upland floodplain	< 0.005	An upland low gradient channel often associated with uplifted plateau areas as occur beneath the eastern escarpment.

2.2 Channel classification

Channel pattern, channel type and reach type were determined for each site. **Channel pattern** relates to the number of channels (single-thread or multiple-thread) and the sinuosity. Sinuous channels show clear meanders within the valley floor sediments whilst straight channels follow the lines of the valley floor - (Single or multiple, straight or sinuous).

Channel type: River channels may be classified into two broad types: bedrock channels and alluvial channels (Rowntree and Wadeson 1999, 2000), with a mixture also occurring.

- *Bedrock*: bedrock bed
- *Mixed bedrock and alluvial*: mixture of bedrock and alluvial beds, with dominant bed material(s) of sand, gravel, cobble and/or boulder.
- *Alluvial with dominant type(s)*: alluvial bed, with dominant bed material(s) of sand, gravel, cobble and/or boulder.

Reach type: Depends on channel type (Table 2.3).

Table 2.3 Summary of reach types found in alluvial and bedrock-controlled systems modified from Rowntree and Wadeson 1999, 2000)

Reach Type	Descriptions
Alluvial systems	
Step-Pool	Characterised by large clasts that are organised into discrete channel spanning accumulations that form a series of steps (cobble or boulder) separating pools containing finer material
Plane-Bed	Characterised by plane-bed morphologies in cobble or small boulder channels lacking well-defined bedforms; randomly scattered cobble or small boulders; no clear pattern
Pool-Riffle	Characterised by an undulating bed that defines a sequence of bars (riffles) and pools.
Pool-rapid	Channels are characterised by long pools backed up behind channel spanning steep boulder deposits forming rapids
Regime	Occur in either sand or gravel. The channel exhibits a succession of bedforms with increasing flow velocity. The channel is characterised by low relative roughness. Plane-bed morphology, sand waves, mid-channel bars or braid bars may all be characteristic.
Bedrock-controlled systems	
Cascade	High-gradient streams dominated by waterfalls, cataracts, plunge pools and bedrock pools. May include bedrock core step-pool features
Flat Bedrock	Predominantly bedrock channel with a relatively smooth bed. Significant falls or rapids are absent.
Bedrock Fall	A steep channel where water flows directly on bedrock with falls and plunge pools
Pool-Rapid	Channels are characterised by long pools backed up behind channel-spanning bedrock intrusions with sufficient gradient to form rapids

2.3 Condition of local catchment

This section is aimed at assessing the condition of a site and catchment upstream (approx. 5 kms along the river) of the site. The condition of the local catchment is assessed during the initial site assessment and only modified if changes in land-use or channel modifications occur between assessments. It incorporates information pertaining to land-use, channel condition and habitat integrity.

The extent of each **land-use** (e.g. agriculture-livestock, rural development, agriculture - crops, etc.), within and beyond the riparian zone, was rated using a standard scale of 0 to 4. (Rating Scale: 0 - None: none in vicinity of site, no discernible impact; 1 - Limited: limited to a few localities, impact minimal; 2 - Moderate: land-use generally present, impact noticeable; 3 - Extensive: land-use widespread, impact significant, small areas unaffected; 4 - Entire: land-use 100% in area, impact significant). The potential impact of each land-use on river health was also rated.

The extent of **in-channel and bank modifications** (e.g. bridge, causeway, etc.) affecting the site was rated using the same scale. The distance upstream or downstream was estimated if appropriate. If the modification was at the site, the distance was given as zero.

The **Index of Habitat Integrity** (IHI, Kleynhans 1999) assesses the number and severity of anthropogenic perturbations on a river and the damage they potentially inflict on the habitat integrity of the system. These disturbances include abiotic factors, such as water abstraction, weirs, dams, pollution and dumping of rubble, and biotic factors, such as the presence of alien plants and aquatic animals which modify habitat. It should be noted that any site-based assessment will lack longitudinal continuity and therefore may not adequately reflect the habitat integrity of the river. Aspects considered in the assessment comprise those instream and riparian zone perturbations regarded as primary causes of degradation of a river ecosystem. The severity of each of these impacts is assessed, using scores as a measure of impact (Table 2.4). Whilst it is near impossible to remove all subjectivity involved in making Index of Habitat assessments, descriptions of each criterion are provided to assist with the assessment (Table 2.5).

Weightings and calculation of instream and riparian status

Once a score has been allocated to an impact, it is moderated by a weighting system, devised by Kleynhans (1996, 1999). Assignment of weights is based on the relative threat of the impact to the habitat integrity of the riverine ecosystem. The total score for each impact is equal to the assigned score multiplied by the weight of that impact (Table 2.6). Based on the relative weights of the criteria, the impacts of each criterion are estimated as follows: Rating for the criterion /maximum value (25) x the weight (percent). *Example*: for a criterion that receives a rating of 10 in the assessment, with a weighting of 14, the impact score is calculated as follows:

$$10/25 \times 14 = 5.6$$

The estimated impacts of all criteria calculated in this way are summed, expressed as a percentage and subtracted from 100 to arrive at a status score for the instream and riparian components, respectively. The Index of Habitat Integrity scores (%) for the instream and riparian zone components are then used to place these two components into a specific class. These classes are indicated in Table 2.7.

Table 2.4 Summary of the scoring procedures used to determine the Index of Habitat Integrity.

Impact Class	Description	Score
None	No discernible impact or the modification is located in such a way that it has no impact on habitat quality, diversity, size and variability.	0
Small	The modification is limited to very few localities and the impact on habitat quality, diversity, size and variability is limited.	1 - 5
Moderate	The modifications are present at a small number of localities and the impact on habitat quality, diversity, size and variability are fairly limited.	6 - 10
Large	The modification is generally present with a clearly detrimental impact on habitat quality, diversity, size and variability. Large areas are, however, not affected.	11 - 15
Serious	The modification is frequently present and the habitat quality, diversity, size and variability in almost the whole of the defined area are affected. Only small areas are not influenced.	16 - 20
Critical	The modification is present overall with a high intensity. The habitat quality, diversity, size and variability in almost the whole of the defined section are influenced detrimentally.	21 - 25

Table 2.5 Instream and riparian criteria used to develop the Index of Habitat Integrity. Each criterion is weighted.

Instream Criteria	Wgt	Riparian Zone Criteria	Wgt
Water abstraction	14	Water abstraction	13
Flow modification	7	Flow modification	7
Bed modification	13		
Channel modification	13	Channel modification	12
Water quality	14	Water quality	13
Extent of inundation	10	Extent of inundation	11
Presence of exotic macrophytes	9	Decrease of indigenous vegetation from the riparian zone	13
Presence of exotic fauna	8	Exotic vegetation encroachment	12
Solid waste disposal	6	Bank erosion	14

Table 2.6 Descriptions of criteria used in the IHI assessment (Kleynhans 1996, 1999).

Criterion	Description
Water abstraction	Direct abstraction from within the specified river/river reach as well as upstream (including tributaries) must be considered (excludes indirect abstraction by for example exotic vegetation). The presence of any of the following can be used as an indication of abstraction: cultivated lands, water pumps, canals, pipelines, cities, towns, settlements, mines, impoundments, weirs, industries. Water abstraction has a direct impact on habitat type, abundance and size; is implicated in flow, bed, channel and water quality characteristics; and riparian vegetation may be influenced by a decrease in water quantity.
Flow modification	This relates to the consequence of abstraction or regulation by impoundments. Changes in temporal and spatial characteristics of flow such as an increase in duration of low flow season can have an impact on habitat attributes, resulting in low availability of certain habitat types or water at the start of the breeding, flowering or growing season.
Bed modification	This is regarded as the result of increased input of sediment from the catchment or a decrease in the ability of the river to transport sediment. The effect is a reduction in the quality of habitat for biota. Indirect indications of sedimentation are stream bank and catchment erosion. Purposeful alteration of the stream bed, e.g. the removal of rapids for navigation is also included. Extensive algal growth is also considered to be bed medication.
Channel modification	This may be the result of a change in flow which alters channel characteristics causing a change in instream and riparian habitat. Purposeful channel modification to improve drainage is also included.
Water quality	The following aspects should be considered; untreated sewage, urban and industrial runoff, agricultural runoff, mining effluent, effects of impoundments. Ranking may be based on direct measurements or indirectly via observation of agricultural activities, human settlements and industrial activities in the area. Water quality is aggravated by a decrease in the volume of water during low or no flow conditions.
Extent of inundation	Destruction of instream habitat (e.g. riffle, rapid) and riparian zone habitat through submerging with water by, for example, construction of an in-channel impoundment such as a dam or weir. Leads to a reduction in habitat available to aquatic fauna and may obstruct movement of aquatic fauna; influences water quality and sediment transport.
Presence of exotic aquatic fauna	The disturbance of the stream bottom during exotic fish feeding may influence, for example, the water quality and lead to increased turbidity. This leads to a change in habitat quality.
Presence of exotic macrophytes	Exotic macrophytes may alter habitat by obstruction of flow and may influence water quality. Consider the extent of infestation over instream area by exotic macrophytes, the species involved and its invasive abilities.
Solid waste disposal	The amount and type of waste present in and on the banks of a river (e.g. litter, building rubble) is an obvious indicator of external influences on stream and a general indication of the misuse and mismanagement of the river.

Criterion	Description
Decrease of indigenous vegetation from the riparian zone	This refers to physical removal of indigenous vegetation for farming, firewood and overgrazing. Impairment of the riparian buffer zone may lead to movement of sediment and other catchment runoff products (e.g. nutrients) into the river.
Exotic vegetation encroachment	This excludes natural vegetation due to vigorous growth, causing bank instability and decreasing the buffering function of the riparian zone. Encroachment of exotic vegetation leads to changes in the quality and proportion of natural allochthonous organic matter input and diversity of the riparian zone habitat is reduced.
Bank erosion	A decrease in bank stability will cause sedimentation and possible collapse of the river bank resulting in a loss or modification of both instream and riparian habitats. Increased erosion can be the result of natural vegetation removal, overgrazing or encroachment of exotic vegetation.

Table 2.7 Habitat Integrity classes (from Kleynhans 1999)

Class	Description	Score (% Of Total)
A	Unmodified, natural.	90 - 100
B	Largely natural with few modifications. A small change in natural habitats and biota may have taken place, but the assumption is that ecosystem functioning is essentially unchanged.	80 - 89
C	Moderately modified. A loss or change in natural habitat and biota has occurred, but basic ecosystem functioning appears predominately unchanged.	60 - 79
D	Largely modified. A loss of natural habitat and biota and a reduction in basic ecosystem functioning is assumed to have occurred.	40 - 59
E	Seriously modified. The loss of natural habitat, biota and ecosystem functioning is extensive.	20 - 39
F	Modifications have reached a critical level and there has been an almost complete loss of natural habitat and biota. In the worst cases, the basic ecosystem functioning has been destroyed.	0 - 19

2.4 General, stream dimensions and substratum composition

General information pertaining to the site at the time of the assessment was recorded, including the water level, preceding rainfall events and extent of canopy cover.

Water level at time of sampling:

Water level	Description
Dry	No water flowing
Isolated pools	Pools that have a trickle of water between them, but no evident flow
Low flow	Water well within the active channel; water probably not touching the riparian vegetation
Moderate flow	Water within the active channel; water likely to be touching riparian vegetation in places
High flow	Water filling the active channel; water completely into riparian vegetation
Flood	Water above active channel

Significant rainfall in last week: The presence and extent of any rainfall event preceding the site visit that was likely to have raised the water level was indicated.

Canopy Cover: The extent of cover of riparian vegetation over the stream: Open, Partially open or Closed canopy, was estimated.

Stream dimensions: The width of the macro-channel, active-channel and river width, and the height of the left and right bank were estimated at each site (left bank is as one is facing downstream). The dominant deep- and shallow-water biotopes were noted.

Macro-channel width	The outer channel of a compound channel; bank top is well above "normal" flood levels but may be inundated infrequently (e.g. once in 20 years).
Active channel width	The area of the channel(s) that has been inundated at sufficiently regular intervals to maintain channel form and to keep the channel free of established terrestrial vegetation.
Water surface width	The width of wetted section of the river from bank to bank at 90º to the direction of flow (i.e. the actual water width).
Bank height	The height from surface of water to top of bank. Estimate left (facing downstream) and right banks separately.
Deep-water physical biotope	Average depth of dominant deep-water area that is > 0.5 m deep (e.g. pool or deep run). Record the type of biotope e.g. pool, backwater, etc.
Shallow-water physical biotope	Average depth of dominant shallow-water area that is < 0.5 m deep (e.g. riffle, run). Record the type of biotope e.g. cobble riffle, bedrock rapid, cascade, etc.

Substratum composition: The abundance of each substrate type (bedrock, boulder, cobble, pebble, gravel, sand, silt/mud/clay) for the stream bed and bank were estimated using a rating scale (0 - absent; 1 - rare; 2 - sparse; 3 - common; 4 - abundant; 5 - entire). Size classes for each substratum type have been modified from the Wentworth grade scale and are given in the linked table. Units are in mm.

Material	Size class (mm)
Bedrock	
Boulder	> 256
Cobble	100 – 256
Pebble	16 – 100
Gravel	2 – 16
Sand	0.06 – 2
Silt / mud / clay	< 0.06

Degree of embeddedness of substratum (%):

The degree of embeddedness, i.e. deposition of fine grains around coarse particles (e.g. sand around cobbles) was estimated for each site. Ranges included: 0 -25, 26-50m 51-75, 76-100.

2.5 Water quantity (flow) and quality (water chemistry)

Stream **velocity** (ms^{-1}) and **depth** (m) was measured at intervals across the surface water for the calculation of discharge (m^3s^{-1}). In instances where the river conditions prevented these measurements being taken, e.g. very deep and or fast flowing water, discharge was estimated using available discharge data for nearby flow gauging and hydropower stations. Spot measurements of velocity and depth were also taken in specific biotopes, particularly stones-in-current.

Physico-chemical parameters were either measured *in situ* (at the site) or water was collected for later analysis of specific physico-chemical parameters. Where possible, instruments were positioned in clearly-flowing points of the river, otherwise the location of meter and hydraulic biotope type were noted. *In situ* variables measured included pH, conductivity, temperature, dissolved oxygen, % O_2 saturation. The presence of algae and/or exotic macrophytes was noted. Turbidity was assessed visibly using the following descriptions.

- *Clear:* water transparent, riverbed visible.
- *Discoloured:* water clear, but with a definite tinge to it, usually brown, green or cloudy (riverbed still visible).
- *Opaque:* water cloudy, riverbed not visible.

- *Silty:* usually after a rainfall event, when silt loads are elevated.

One-litre grab samples were taken from fast running water and stored in polyethylene bottles. Samples for nitrate, nitrite and ammonia were filtered before the analysis. Most of these were analysed on the same day, but some were frozen and analysed after two days. The remaining samples were frozen for the analysis of the other parameters. Details of the laboratory analyses performed for each variable are provided in Appendix B. The trophic status classes for nutrients and typical symptoms associated with each class are indictated below:

- Oligotrophic conditions; usually moderate levels ofspecies diversity; usually low productivity systems withrapid nutrient cycling; no nuisance growth of aquaticplants or blue-green algae.
- Mesotrophic conditions; usually high levels of speciesdiversity; usually productive systems; nuisance growthof aquatic plants and blooms of blue-green algae; algalblooms seldom toxic.
- Eutrophic conditions; usually low levels of speciesdiversity; usually highly productive systems, withnuisance growth of aquatic plants and blooms of blue-green algae; algal blooms may include species which aretoxic to man, livestock and wildlife.
- Hypertrophic conditions; usually very low levels ofspecies diversity; usually very highly productivesystems; nuisance growth of aquatic plants and bloomsof blue-green algae, often including species which aretoxic to man, livestock and wildlife.

2.6 Invertebrates

Invertebrates are largely dependent on the aquatic environment in which they live, and are therefore frequently used as indicators of the general ecological condition, also referred to as river or ecosystem health. They are sensitive to factors such as water quality, water quantity (environmental flows), habitat availability and food availability. As a group, invertebrates have several characteristics that make them useful indicator organisms. They are ubiquitous (widespread, common) and diverse, and are therefore affected by a variety of disturbances in many different types of aquatic habitats. Sensitivity to stress varies with species and the large number of species within an assemblage offers a spectrum of responses to environmental stresses. In their aquatic phase, invertebrates are largely non-mobile and are thus representative of the location being sampled, which allows effective spatial analyses of disturbance. They have relatively long life cycles compared to other groups (e.g. planktonic organisms), which allows elucidation of changes over time (temporal).

Invertebrates were sampled using the rapid bioassessment method, SASS5 (South African Scoring System, Version 5, Dickens and Graham 2002). It was developed in South Africa in response to a need by water resource managers for a quick and cost-effective method by which water quality in rivers could be assessed. The method was not designed to enable the exact nature of the impairment to be determined, but rather acts as a red flag indicating that there is a water quality or general river health problem (Dallas 1997). A detailed description of the SASS protocol (version 5) is given in Dickens & Graham (2002).

This study is the first time this method has been applied in the Pangani River Basin (and possibly Tanzania) and thus some regional validation may be required. The present study should provide insight as to the applicability of the method in the Pangani River Basin. Nonetheless, in the present form, SASS should provide a reasonable indication of the health of the river based on aquatic macroinvertebrates.

Three aspects are considered when applying the SASS method, including:

- an assessment of the biotopes present at the site,
- an assessment of the invertebrates present in each biotope (SASS5), and

- an assessment of the biotopes sampled (IHAS).

Biotopes present: The general river make-up, i.e. pool, run, riffle or a combination thereof, was recorded for each site. This provides an indication of biotope diversity. The abundance of each SASS and specific biotope type was estimated using the following scale: 0 – absent; 1 – rare; 2 – sparse; 3 – common; 4 - abundant; 5 – entire. *Specific biotopes* provide further details of the types of biotope within each SASS biotope. Descriptions of some of these have been extracted from Rowntree and Wadeson (1999, 2000). Biotopes have been grouped into two types, namely SASS biotopes and specific biotopes. They relate to the type of habitat available for habitation by aquatic organisms as well as the hydraulic conditions in some instances. SASS biotopes are based on those described in the SASS5 protocol (Dickens and Graham 2002). For stones in and out of current, it is important to record if the substrate is bedrock.

SASS biotopes		Description
Stones In Current	SIC	Stones in flowing water, may include bedrock
Stones Out Of Current	SOOC	Stones out of any perceptible current (with visible silt seen accumulating on stone surfaces), may include bedrock
Marginal Vegetation In Current	MV-IC	Emerged and submerged vegetation in fast current; at the river's edge or on the edge of in-channel islands
Marginal Vegetation Out Of Current	MV-OC	Emerged and submerged vegetation out of any perceptible current; at the river's edge or on the edge of in-channel islands
Aquatic Vegetation	AQV	Submerged or partially submerged vegetation within the channel, normally in flowing water
Gravel	G	Stones < 2cm in diameter
Sand	S	Sand grains < 2mm in diameter
Silt/mud/clay	M	Particles < 0.06mm in diameter

SASS Biotope	Specific biotope	Description
SIC	Riffle	Occur over coarse alluvial substrates from gravel to cobble; undular standing waves or breaking standing waves.
	Run	Occur over any substrate e.g. gravel, cobble, boulder; ripple flow but surface of water not broken.
	Boulder rapid	A rapid-like feature made up of large immobile boulders.
	Bedrock	Large sheets of rock.
	Chute	Typically occur in boulder or bedrock channels where flow is being funneled between macro bed elements; smooth boundary turbulent flow exhibiting flow acceleration.
	Cascade	Occur over a substrate of boulder or bedrock. Small cascades may occur in cobble where the bed has a stepped structure due to cobble accumulations. Free falling flow, contact with substrate largely maintained
SOOC	Backwater	A morphologically defined area along-side but physically separated from the channel, connected to it at its downstream end; barely perceptible or no flow.
	Slackwater	An area of no perceptible flow which is hydraulically detached from the main flow but is within the main channel; barely perceptible or no flow.
	Pool	An area with direct hydraulic contact with upstream and downstream water; barely perceptible flow.
	Bedrock	Large sheets of rock.
MV		Grasses, reeds, shrubs, sedges, etc. which are adjacent to the river bank. Also includes floating macrophytes such as water hyacinth, parrot's feather, etc.
AQV		Sedges, moss, trailing grasses, filamentous algae, etc. which are submergent or partially submergent, normally in flowing water.
GSM		Gravel, sand or mud present in backwater, slackwater and/or in-channel, i.e. in

		main flowing part of the channel.

SASS5 is a qualitative, multi-habitat, rapid field-based method that requires identification of invertebrates, mostly to family level. Sensitivity weightings, which have been pre-assigned to individual taxa according to the water quality conditions each taxon is known to tolerate (Dallas 1997), are used to calculate the biotic index. Data interpretation is based on two calculated values, namely SASS5 Score, which is the sum of the sensitivity weightings for taxa present at a site, and Average Score Per Taxon (ASPT), which is the SASS5 Score divided by the number of SASS taxa.

The SASS5 procedure is as follows:

- Kick stones in current (SIC) and bedrock for 2 minutes if stones are loose, maximum 5 minutes if stones immovable. <u>Note that the above times refer to actual kicking time, and not to time spent crossing the river.</u>
- Kick stones out of current (SOOC) and bedrock for 1 minute.
- Samples collected both in and out of current are combined into a single Stones (S) biotope sample.
- A total length of approximately two meters of vegetation must be sampled, spread over one or more locations, especially where different kinds of marginal vegetation are present (e.g. reeds plus grasses) in different flow velocities, and aquatic vegetation for a 1m^2 area.
- Samples collected in and out of current and aquatic vegetation are combined into a single Vegetation (Veg) biotope sample.
- Stir and sweep gravel, sand, mud (GSM) (both in and out of current) for 1 minute total.
- Samples collected in and out of current are combined into a single Gravel/Sand/Mud (GSM) biotope sample.
- Hand picking and visual observation for 1 minute - record in biotope where found (by circling estimated abundance on score sheet).

For each of the 3 major biotopes (Stones, Veg, GSM), tip net contents into tray, remove leaves and twigs, score for 15 minutes per biotope but stop if no new taxa seen after 5 minutes. Estimate abundances as follows: 1 = 1, A = 2-10, B = 10-100, C = 100-1000, D = >1000.

IHAS (Invertebrate Habitat Assessment System) attempts to account for the variability in the amount and quality of SASS biotopes which are sampled. The aim of the IHAS assessment is to record details about the SASS biotopes sampled, which are divided into stones in current, vegetation and other (stones out of current, gravel, sand, mud). A modified version of the method (see Dallas (2007) for details) has been applied in this assessment. The criteria assessed and scored are idicated below:

Stones

- Total length of white water (riffle/rapid) (in metres)
- Total length of submerged stones in current (run) (in metres)
- Number of separate SIC area's kicked (not individual stones)
- Avg stone size kicked (cm); (gravel is <2; bedrock is >20)
- Amount of stone surface clear (of algae, sediment etc.) (%)
- Time spent actually kicking SIC's (in min), (gravel/bedrock = 0 min)
- Stones out of current (SOOC) sampled: (in m^2)

Vegetation

- Length of marginal vegetation sampled (river banks) (in m)
- Amount of aquatic vegetation/algae sampled (underwater) (m^2)
- Marginal vegetation sampled in (IC) or out of current (OOC)

- Type of vegetation (* leafy vegetation as opposed to stems/shoots). (e.g. mostly leafy = >75%; mostly stems/shoots = 1-25%)

Gravel, sand and mud

- Sand sampled: (in mins) ('under' = present, but only under stones)
- Mud sampled: (in mins) ('under' = present, but only under stones)
- Gravel sampled: (in mins) (if all gravel, SIC stone size = '<2')

A reference collection of invertebrate taxa (54) collected during the study has been compiled for the Pangani River Basin. It is a wet collection with specimens stored in 70% alcohol. It is housed by the Pangani Water Basin Office in Moshi. This will assist with the future identification of aquatic invertebrates.

2.7 Fish

Fish sampling was conducted using various fishing gear depending on the habitat conditions and availability. Available fish habitats were recorded based on velocity-depth classes and cover. For each velocity-depth class, the presence of features that provide cover for fish (i.e. refuge from high flow velocity, predators, high temperatures, etc.) were taken into consideration (Kleynhans 1999):

- **Overhanging vegetation:** Thick vegetation overhanging water by approximately 0.3 m and not more than 0.1 m above the water surface. Marginal vegetation is included here.
- **Undercut banks and root wads:** Banks overhanging water by approximately 0.3 m and not more than 0.1 m above the water surface.
- **Stream substrate:** Various substrate components (rocks, boulders, cobbles, gravel, sand, fine sediment and woody debris "snags") that provide cover for fish.
- **Aquatic macrophytes:** Submerged and emergent water plants are included.
- **Water column:** Where there is sufficient water depth, the water column will also function as cover (e.g., in terms of lessening predation from aerial predators).

The relative abundance of both the velocity-depth classes and the cover classes were estimated according to the following guideline: 0=absent; 1=rare; 2=sparse; 3=common; 4=abundant, 5=very abundant.

Details of the velocity-depth classes within which fish sampling normally occurs is given below, together with the recommended sampling gear.

Fish habitat (velocity-depth class)	Description
Slow (<0.3 m/s), shallow (<0.5 m)	This includes shallow pools and backwaters. A small seine net (5 m long, 1.5 m deep, mesh size = 1 mm) is usually used to sample fish. In some instances, an electrical shocking apparatus (AC) can be used. Capture results are recorded as number of fish caught during each effort with a net, or the number of fish caught per time unit (minutes) with an electroshocker.
Slow (<0.3 m/s), deep (>0.5 m)	This includes deep pools and backwaters. A large seine net (e.g. 70 m long, 1.5 m deep, mesh size 2.5 cm) can be used. A cast net (e.g. diameter = 1.85 m, mesh size = 2.5 cm) can be used in pools not suitable for beach seining. Capture results are recorded as number of fish caught during each effort.
Fast (>0.3 m/s), shallow (<0.3 m)	Shallow runs, rapids and riffles fall in this category. An electrical shocking apparatus is used in these habitat types. Capture results are recorded as number of fish caught per time unit (minutes).
Fast (>0.3 m/s), deep (>0.3 m)	Deep runs, rapids and riffles fall under this category. An electrical shocking apparatus is used in these habitat types. Capture results are recorded as number of fish caught per time unit (minutes).

For the present study, limitations with respect to the availability of sampling gear resulted in some velocity-depth classes being sampled together. The sampling gear available included a gill net, a sweep net and a small beach seine. The monofilament gill-net (100m length, 4m depth), which consisted of five 20m panels with stretched mesh sizes of 44mm, 64mm, 75mm, 100mm and 145mm, was set across the river channel for one hour at each site (where habitat allowed). A small inflatable boat was used in setting and hauling the gill net. The sweep net (0.2 mm mesh size) was employed at most of the sites, particularly to catch fish in backwaters under overhanging vegetation, adjacent to the river bank and behind stones. The small beach seine (2m x 1m, mesh size of 0.5mm) was used at some sites. An electro-shocker was used at appropriate sites and habitats during the dry season survey. In addition to fish sampling, fish were collected from fisherman at various sites and information on fish caught obtained from the fisherman. Where possible, the fish that were captured were identified to species level using fish identification field guides by Bernacsek (1980) and Eccles (1992).

2.8 Riparian Vegetation

Vegetation is an integrator of environmental factors in that it reflects the climatic, physiographic, edaphic (i.e. pertaining to or conditioned by soil) and biotic features pertaining to the land on which it grows. An understanding of the vegetation and plants in an area can therefore give good insights into the agricultural or biological potential of the area. Some land-uses also depend directly on the vegetation resource and in this case an inventory of vegetation is of great importance. The main objective of the riparian vegetation survey was to classify and assess the vegetation cover, species composition, identify invasive plant species and describe habitat stratification within the riparian zone (left and right bank). A qualitative approach was used whereby plant species were recorded in the field. The study was confined to the riparian zone at the site but attempted to include upstream and downstream areas when possible (up to 5 kilometres). The width of riparian zone was estimated for the left and right banks. Riparian vegetation was classified into six major physiognomic types including Trees, Shrubs, Reeds, Sedges, Grasses and Bare ground. The vegetation cover of each type was estimated using a rating scale (0 - absent, 1 - rare, 2 - sparse, 3 - common, 4 - abundant and 5 - entire).

Preliminary identification of all plant species was done in the field. For those plants which could not be identified in the field, specimens were collected, pressed in a plant press, dried and taken to the Herbarium, Department of Botany, University of Dar es Salaam for further confirmation with the relevant references and/or matching with herbarium specimens. Voucher specimens were deposited at the Herbarium of the University of Dar es Salaam for future references.

2.9 Overall assessment of river health

A general overview of the river health at each site was obtained following discussion amongst the specialists and a table of the health of each of the components was derived for each site. The components considered included:

- Water quantity/discharge (estimated from discharge and general knowledge on the extent of abstractions)
- Water quality (physico-chemical parameters)
- Index of Habitat Integrity (IHI) - instream (combined with land use and channel modifications)
- Index of Habitat Integrity (IHI) - riparian
- Invertebrates
- Fish
- Riparian vegetation

Following analysis of the data collected for each of the components assessed, a discussion was held to determine the status of each of the components using common classes to indicate the level of modification from an expected natural or baseline condition. These general river health classes were assigned to each of the components based on classes developed in South Africa (Kleynhans 1999, Dallas 2007) and which were verified by team members. Classes ranged from A to D for all components except IHI, which included classes E and F. A brief description of each class is given in Table 2.8.

Table 2.8 River Health Classes for the Pangani River Basin

Class	Description
A	Natural, unmodified system
B	Largely natural, slightly modified system
C	Moderately modified system
D	Largely modified system
E*	Only for IHI - Seriously modified system
F*	Only for IHI - Critically modified system

2.10 Application of river health knowledge to environmental flows

Knowledge gained during the river health assessment was, where possible, used to answer questions related to environmental flows. These are summarised in the discussion section and tabulated in Appendix F.

3 RESULTS AND DISCUSSION

The characteristics of each site are discussed in section 3.1. General trends and analyses are provided in section 3.2.

3.1 Site descriptions and characterisations

The following section provides an overview of the characteristics of each site, including a description of the channel classification and stream dimensions, and provides a photographic record for each during the wet and dry seasons. River health classes for each component are given and key issues associated with each component are highlighted. Sites have been abbreviated: R1 to R13.

R1 - Nduruma River

Zone: Mountain Stream (S03° 22.540'; E36° 45.064', altitude = 1310 m); upstream of Nduruma chini

The Nduruma River originates at Mt Meru (4565masl) and feeds into the Kikuletwa River. At R1 (Figure 3.1 and Figure 3.2) the river has a straight, single thread channel, with a mixed bedrock and alluvial channel type. The substratum is dominated by cobble and boulder, and the reach type is pool-rapid. The summarised river make up was a mix of riffle/rapid and run.

Wet-season:
Macro-channel width was 50 m, active channel width was 20m and surface water width was 8m. The left and right bank heights were 0.5m and >10m respectively. The deep-water physical biotope was a deep run (average depth = 0.75m) and the shallow-water physical biotope was a boulder/cobble riffle (average depth = 0.25m).

View of site - upstream

View of site - from upstream bridge

View of site - downstream

Figure 3.1 R1 - Nduruma River in the wet season

Dry season:
Water levels had dropped since the wet season survey. Surface water width was 5m, deep-water physical biotope was a run (average depth = 0.3m) and the shallow-water physical biotope was a cobble riffle (average depth = 0.1m).

View of site - upstream

View of site - from upstream bridge

View of site - downstream

Figure 3.2 R1 - Nduruma River in the dry season

Assessment of river health

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
C	B	B	F	B	B	C

Discharge: Less than 40% of water was abstracted in the wet season and >80% in the dry season. The dry season flows were reduced and the duration of these dry season flows were extended, with less water in the river generally.

Water quality: Dissolved oxygen (DO) concentrations decreased and Total Phosphorus (TP) increased in the dry season. Trophic status shifted from mesotrophic to eutrophic in the dry season.

Condition of local catchment: R1 was heavily infested with alien vegetation within the riparian zone and beyond - with a moderate potential impact on river health. Weirs within and beyond the riparian zone were considered to have a moderate impact, while cultivation of crops, which was extensive beyond the riparian zone, was considered to have a limited impact on river health. The bridge and weir upstream were mainly responsible for the in-channel and bank modifications but impact was limited. The instream habitat integrity was moderately modified (C score), however, the riparian zone was critically modified (F score). This was based on the index of habitat integrity (IHI), which, in this case, was mainly the result of water abstraction, flow modification, decrease of indigenous vegetation from the riparian zone, exotic vegetation encroachment and bank erosion.

Invertebrates: There was a reasonable diversity of invertebrates in both the wet and dry seasons, with all three biotopes present. *Specific biotopes:* SIC included riffle, run and boulder rapid (wet season only); SOOC were in backwaters and slackwaters; MVIC and MVOC were mostly grasses and shrubs; and gravel, sand and mud occurred in slackwaters. This Mountain Stream site had a reasonable diversity of invertebrates (23 taxa recorded) in both the wet and dry seasons, with all three biotopes present. Four families of mayflies were recorded, as well as dragonflies, caddisflies, beetles and flies.

Wet Season

	SASS5 Score	Number of Taxa	ASPT	Taxa recorded
Stones	71	9	7.89	Baetidae >2 Sp, Caenidae, Heptageniidae, Tricorythidae, Coenagrionidae, Aeshnidae, Libellulidae, Corixidae, Naucoridae, Hydropsychidae 2 Sp, Leptoceridae, Dytiscidae, Gyrinidae, Psephenidae, Ceratopogonidae, Chironomidae and Simuliidae
Veg	64	13	4.92	
GSM	22	4	5.50	
Combined	110	17	6.47	

Dry Season

	SASS5 Score	Number of Taxa	ASPT	Taxa recorded
Stones	76	10	7.60	Potamonautidae, Baetidae >2 Sp, Caenidae, Heptageniidae, Tricorythidae, Aeshnidae, Gomphidae, Naucoridae, Veliidae, Hydropsychidae 1 Sp, Leptoceridae, Gyrinidae, Athericidae, Chironomidae, Simuliidae and Tipulidae
Veg	53	8	6.63	
GSM	24	4	6.00	
Combined	106	16	6.63	

Fish: Habitat was limited to fast flowing, shallow areas and deeper runs. One fish species was caught, *Garra dembeensis*, which is adapted to living in fast flowing streams.

Riparian Vegetation: The riparian width was 30m on the right hand bank and 5m on the left hand bank. Fifty-two species were recorded with trees, shrubs, sedges and grasses all represented. Encroachment by exotic vegetation was widespread and smaller areas were invaded by terrestrial plants.

R2 - Kikuletwa River

Zone: Upper Foothill (S03° 33.469'; E36° 57.993', altitude = 920m); upstream of Wahoga chini (gauging station)

Above this site the Kikuletwa River (Figure 3.3 and Figure 3.4) is joined by the Nduruma and Tengeru Rivers and associated tributaries. At R2 the river has a straight, single thread channel, with an alluvial channel type. The substratum was dominated by silt and clay, and the reach type was pool-riffle, the riffle being created by small sections of boulder and cobble. The summarised river make up was a mix of riffle/rapid, run and pool.

Wet-season:

Macro-channel width was approx. 100 m, active channel width was 40m and surface water width was 8m. The left and right bank heights were 5m and 3.5m respectively. The deep-water physical biotope was a pool (average depth = 1.5m) and the shallow-water physical biotope was a cobble riffle (average depth = 0.5m).

Figure 3.3 R2 - Kikuletwa River in the wet season

Dry season:
The river had dried up and there was zero flow. An isolated pool remained at the uppermost point.

Assessment of river health

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
D	D	D	F	D	D	D

Discharge: The river at this site was no longer perennial and in the dry season it dried up. Floods were smaller but the number of floods has remained the same when compared to historical events.

Water quality: An extremel high turbidity value was recorded at this site in the Upper Foothill zone. This is most likely due to removal of riparian vegetation and extensive livestock farming in the area.

Condition of local catchment: The extensive potential impact on the river health at R2 was mainly attributable to agriculture and livestock, within and beyond the riparian zone. Return flow from irrigation, alien vegetation infestation, roads, rural development and recreational activities in the local catchment were considered to have a limited impact. The impact by the weirs upstream to in-channel and bank modifications was limited. Downstream the low flow bridges and gravel roads in the riparian also had a limited impact. The IHI score indicated that the instream habitat integrity was largely modified (D score), while the riparian zone was critically modified (F score). The scores were largely caused by water abstraction, flow modifications, decrease of indigenous vegetation in the riparian zone and bank erosion.

View of site - upstream showing remaining isolated pool

Riffle biotope - dry

Pool habitat

Substratum: gravel, pebbles and cobble

Figure 3.4 R2 - Kikuletwa River in the dry season

Invertebrates: This Upper Foothill site showed indications of a loss of invertebrates, with lower SASS5 Scores in comparison to the other Upper Foothill site (R5). *Specific biotopes:* SIC included riffle and run; SOOC were in pools, MVOC were all grasses; and gravel, sand and mud occurred in backwaters and/or slackwaters (wet season only). A total of 15 taxa were recorded in the wet season - the site was dry during the dry season. Stones biotope was limited, although 2 families of mayflies were recorded in it. The marginal vegetation supported the greatest diversity of invertebrates, even though it had been severely reduced at the site. No dragonflies were recorded and most vegetation dwellers were bugs, and thus air-breathers. Worms (Oligochaetes) were recorded in the mud.

Wet Season

	SASS5 Score	Number of Taxa	ASPT	Taxa recorded
Stones	33	4	8.25	Oligochaeta, Baetidae >2 Sp, Caenidae, Heptageniidae, Coenagrionidae, Belastomatidae, Corixidae, Gerridae,
Veg	54	11	4.91	

GSM	15	4	3.75	Hydrometridae, Naucoridae, Notonectidae, Vellidae, Hydropsychidae 2 Sp, Dytiscidae and Chironomidae
Combined	81	15	5.40	

Fish: In the wet season, habitat was limited to fast deep areas, with some overhanging vegetation, undercut banks, gravel substrate and water column. One species was recorded, *Clarius gariepinus*, although fisherman indicate that two additional species of *Tilapia* also occur.

Riparian Vegetation: The riparian zone at the sampling point was almost bare due to removal of riparian vegetation and livestock watering. Downstream of the site, the riparian width was 40m on the right hand bank and 30 on the left hand bank. Thirty-three species were recorded with trees, shrubs, sedges and grasses were represented. Encroachment by exotic vegetation and terrestrial plants was limited.

R3 - Kikuletwa River

Zone: Lower Foothill (S03° 38.564'; E37° 21.235', altitude = 703m); upstream of Nyumba ya Mungu, below TPC

Above this site the Kikuletwa River (Figure 3.5 and Figure 3.6) is joined by the Chemka, Kware, Sanya, Karanga, Weruweru and Kikafu Rivers, which drain the western slopes of Mt Kilimanjaro. At R3 the river has a multiple thread, sinuous channel, located within a broader floodplain. It has a mixed bedrock and alluvial channel with gravel as the dominant substratum. The reach type was flat bedrock with a relatively smooth bed and no significant falls or rapids. However, the gravel deposited in the bedrock suggests the reach type could also be considered regime, which also occurs in sand or gravel dominated systems. The summarised river make up was a run only in the wet season, becoming a mix of riffle/rapid, run and pool in the dry season.

Wet-season:

Macro-channel width was approx. 2000 m (including the floodplain), active channel width was 50m and surface water width was 20m. The left and right bank heights were 3m and 4m respectively. The deep-water physical biotope was a deep run (average depth = 1.5m) and the shallow-water physical biotope was a bedrock run (average depth = 0.4m).

Dry season:

Water levels had dropped since the wet season survey. Surface water width was 3m, deep-water physical biotope was a pool (average depth = 0.3m) and the shallow-water physical biotope was a cobble/gravel riffle (average depth = 0.2m).

Assessment of river health

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
C/D	B/C	D	E	B	C	C

Discharge: The river at this site had substantially less water during the dry season compared to the wet season. The floods have not changed significantly in terms of size or frequency. Dry season flows were extended beyond the expected dry season and the river was perennial because it is sustained by the Chemka Springs upstream.

Water quality: Conductivity, carbonates/bicarbonates, magnesium and Total Phosphorus increased in the dry season.

Condition of local catchment: The local catchment was mostly affected by the presence of livestock within and beyond the riparian zone, though its potential impact on river health was limited. The wilderness area was widespread and extensive especially beyond the riparian zone. The in-channel and bank modifications were only attributed to gravel roads within the riparian zone with a limited impact. The IHI score was mainly driven by water abstractions, flow modifications, water quality and removal of indigenous vegetation from the riparian zone and bank erosion. The scores translated to a largely and seriously modified system for instream and riparian zone respectively (D and E score).

View of site - upstream

View of site - downstream

Snag habitat - resembles Stones-in-current habitat

Human and livestock use of the river

Figure 3.5 R3 - Kikuletwa River in the wet season

Invertebrates: This Lower Foothill site had a diverse invertebrate fauna in the wet season (19 taxa), but fewer in the dry season (11 taxa). Generally, the stones biotope was limited to bedrock with gravel and pebbles, although fallen trees (termed snags) in the river resembled the stones biotope and were also sampled in the wet season. *Specific biotopes:* SIC included run and bedrock rapid in the wet season, and riffle and run in the dry season; SOOC were in slackwaters and pools (dry season only). In the dry season the river was shallower and gravel/cobble riffle biotope was available. No vegetation habitat was available during the dry season. Mud occurred in backwaters and slackwaters. A total of 25 taxa were recorded. The fauna included worms, crabs, water-mites, mayflies, dragon- and damselflies, bugs, caddisflies, beetles and flies. Of note was the only record of the caddisfly family, Ecnomidae, in the wet-season survey.

Wet Season

	SASS5 Score	Number of Taxa	ASPT	Taxa recorded
Stones	82	14	5.86	Oligochaeta, Baetidae >2 Sp, Leptophlebiidae, Chlorocyphidae, Coenagrionidae, Corduliidae, Gomphidae, Libellulidae, Belastomatidae, Corixidae, Hydrometridae, Naucoridae, Vellidae, Ecnomidae, Hydropsychidae 2 Sp, Dytiscidae, Gyrinidae, Chironomidae and Simulidae
Veg	40	8	5.00	
GSM	24	6	4.00	
Combined	109	19	5.74	

Dry Season

	SASS5 Score	Number of Taxa	ASPT	Taxa recorded
Stones	55	9	6.11	Potamonautidae, Hydracarina, Baetidae 2 Sp, Caenidae, Leptophlebiidae, Tricorythidae, Libellulidae, Corixidae, Hydropsychidae 2 Sp, Elmidae, Gyrinidae and Chironomidae
Veg	-	-	-	
GSM	16	4	4.00	
Combined	69	12	5.70	

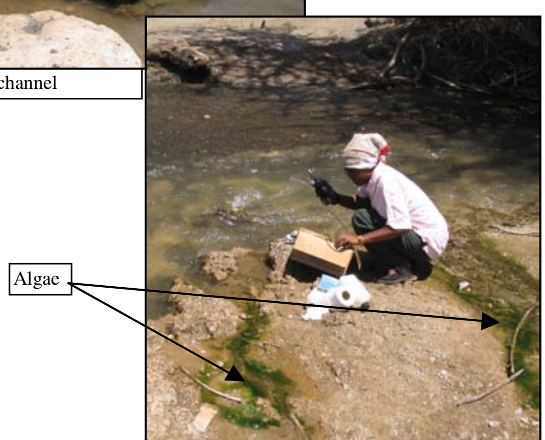
View of site

View of site - upstream

View of site - downstream

Calcareous rocks in channel

Shallow gravel/cobble riffle area



Measuring physico-chemical parameters

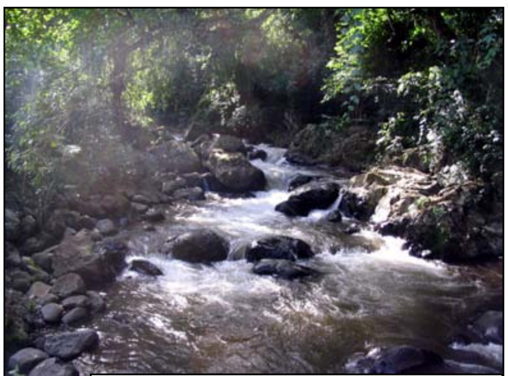
Figure 3.6 R3 - Kikuletwa River in the dry season

Fish: In the wet season, habitat was limited to fast, deep areas and in the dry season to fast and slow, shallow areas. There was overhanging vegetation, undercut banks, gravel and rocky substrate and water column. Five species were recorded (2 extra – fisherman).
Riparian Vegetation: The riparian zone was divided into riparian and floodplain, with widths 50m, 50m on the right hand bank and 40m, 90m on the left hand bank for riparian and floodplain respectively. Twenty species were recorded and trees, shrubs, reeds, sedges and grasses were represented. There was no encroachment by exotic vegetation, reeds or terrestrial plants.

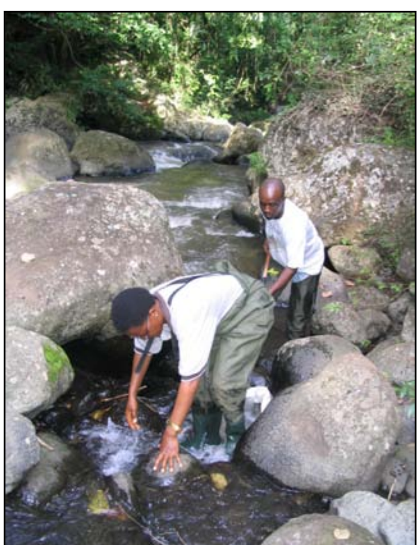
R4 - Ona River

Zone: Mountain Stream (S03° 18.861'; E37° 30.925', altitude = 1166m); at Samangai-Kimatoloni bridge

The Ona River (Figure 3.7 and Figure 3.8) originates on the central slopes of Kilimanjaro and feeds into the Himo River. At R4 the river has a straight, single thread channel, with a mixed bedrock and alluvial channel type. The substratum was dominated by bedrock and boulder, and the reach type was predominantly bedrock fall, although upstream and downstream of the site pool-rapid reach type was also present. The summarised river make up was a rapid and run in the wet season, becoming a mix of riffle/rapid, run and pool in the dry season.


View of site - upstream from footbridge


Upstream boulder/bedrock rapids/cascades


Sampling the stones biotope


View downstream from footbridge

Figure 3.7 R4 - Ona River in the wet season

Wet-season:
Macro-channel and active channel widths were 20m and surface water width was 10m. The left and right bank heights were both >10m. The deep-water physical biotope was a deep run (average depth = 1m) and the shallow-water physical biotope was a bedrock rapid (average depth = 0.25m).

Dry season:
Water levels had dropped since the wet season survey. Surface water width was 5.5m, deep-water physical biotope was a run (average depth = 0.75m) and the shallow-water physical biotope was a bedrock rapid (average depth = 0.2m).


View of site - upstream from footbridge


Upstream boulder/bedrock rapids/cascades


Silt deposition in slackwater and backwater areas


Measuring discharge


Silt deposition in slackwater and backwater areas

Figure 3.8 R4 - Ona River in the dry season

Assessment of river health

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
B/C	A/B	B	C	A	A/B	B

Discharge: The river at this site was perennial, although dry season flows were lower than wet season flows. There was abstraction for local farming.

Water quality: The water quality at this represents the near-natural condition. There were no apparent changes from wet to dry season.

Condition of local catchment: R4 was dominated by wilderness areas in the riparian zone and agricultural crops like banana, coffee and maize beyond the riparian zone. The potential impact of the crops on river health was limited. Rural development was moderate and beyond the riparian zone, with a limited impact, while alien vegetation infestation within and beyond the riparian zone was limited. There were no in-channel and bank modifications except for a foot bridge downstream, which was considered to have no impact. Water abstraction, flow modifications, and exotic plants were the main drivers of the IHI resulting in a largely natural flow (class B) with few modifications for instream and a moderately modified riparian zone (class C).

Invertebrates: This Mountain Stream site only had stones biotope for sampling. *Specific biotopes:* SIC included riffle, run, boulder and bedrock rapids, chutes and cascades; SOOC were in backwaters and slackwaters; MVIC and MVOC were mostly grasses (wet season only); gravel and sand occurred in slackwaters and in channel; and mud in slackwaters. It had the highest SASS5 Score for this biotope (in both seasons) compared to all other sites assessed. Flatworms, crabs and water-mites, four families of mayflies, as well as dragonflies, bugs, caddisflies, beetles (including Elmidae and Psephenidae) and flies. A total of 16 taxa were recorded.

Wet Season

	SASS5 Score	**Number of Taxa**	**ASPT**	**Taxa recorded**
Stones	109	16	6.81	Turbellaria, Potamonautidae, Hydracarina, Baetidae >2 Sp, Heptageniidae, Leptophlebiidae, Tricorythidae, Gomphidae, Libellulidae, Vellidae, Hydropsychidae 2 Sp, Leptoceridae, Elmidae, Psephenidae, Chironomidae and Simulidae
Veg	-	-	-	
GSM	-	-	-	
Combined	109	16	6.81	

Dry Season

	SASS5 Score	**Number of Taxa**	**ASPT**	**Taxa recorded**
Stones	90	12	7.5	Potamonautidae, Hydracarina, Baetidae >2 Sp, Heptageniidae, Leptophlebiidae, Tricorythidae, Vellidae, Hydropsychidae 2 Sp, Elmidae, Psephenidae, Chironomidae and Simulidae
Veg	-	-	-	
GSM	-	-	-	
Combined	90	12	7.5	

Fish: Habitat was largely limited to fast, deep and fast, shallow areas. There were large amounts of overhanging vegetation (trees), few undercut banks, rocky substrate and water column. Two species were recorded, although fisherman indicated that an additional species is present.

Riparian Vegetation: The riparian width was 70m on the right hand bank and 80m on the left hand bank. Forty-nine species were recorded and trees, shrubs and grasses were represented. There was no encroachment by exotic vegetation.

R5 - Himo River

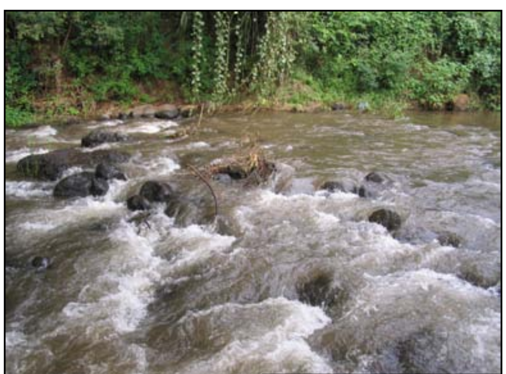
Zone: Upper Foothill (S03° 23.448'; E37° 32.611', altitude = 868m); at Himo town, upper bridge (gauging station)

The Himo River (Figure 3.9 and Figure 3.10) is fed by the Ona River and then joins the Ruvu River downstream. At R5 the river has a straight, single thread channel, with a mixed bedrock and alluvial channel type. The substratum was dominated by cobble and boulder, and the reach type was pool-rapid. The summarised river make up was a mix of riffle/rapid, run and pool.

Wet-season:

Macro-channel width was approx. 100 m, active channel width was 20m and surface water width was 10.5m. The left and right bank heights were 5m and 10m respectively. The deep-water physical biotope was a pool (average depth = 1.5m) and the shallow-water physical biotope was a boulder/cobble rapid (average depth = 0.3m).

View of site



Boulder/cobble rapid

Downstream pool - fish sampling

Figure 3.9 R5 – Himo River in the wet season

Dry season:

Water levels had dropped since the wet season survey. Surface water width was 7m, deep-water physical biotope was a pool (average depth = 1.0m) and the shallow-water physical biotope was a cobble riffle (average depth = 0.15m).

Assessment of river health

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
C	C	D	C	C	C	C

Discharge: The river at this site was perennial, although flows were substantially lower in the dry season compared to the wet season. The dry period was extended beyond the expected dry season. There was water abstraction (Himo town nearby).

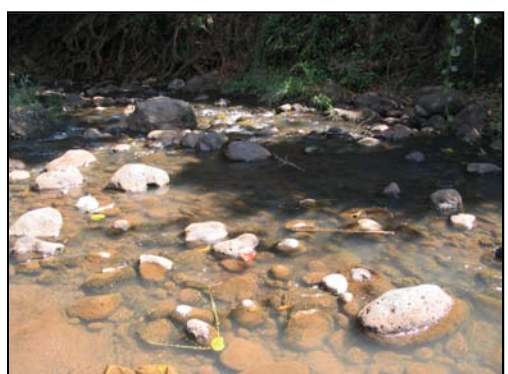
Water quality: Temperature increased with lower flows and silt was deposited on stones. Sources of water quality impairment result from localized use of the river by people from the town of Himo, e.g. washing cars, clothes, bathing. Bacterial contamination (faecal coliforms) is likely to be a problem - this may impact upon human health.

View of site

Wet season boulder rapid reduced to boulder/cobble riffle

Downstream pool

Marginal vegetation biotope



Deposition of silt in slow flowing areas

Figure 3.10 R5 – Himo River in the dry season

Condition of local catchment: The agricultural crops like banana, maize, coffee etc. dominated the local catchment extensively beyond the riparian zone with a moderate potential impact on river health. Livestock was limited within and beyond the riparian zone, whereas irrigation was moderate, though the impact for both was considered limited. Rural development had a moderate effect within the riparian zone mainly because of washing in the river. Beyond the riparian zone rural development was extensive (town of Himo), with an overall impact rated as extensive. In-channel and bank modifications were contributed mainly by extraction of gravel, cobble and/or sand upstream with a moderate impact, while the impact of the gravel road within the riparian zone was considered limited. According to the IHI score the local catchment was classified as largely modified and moderately modified (classes D and C respectively) for instream and riparian - a score attributable mainly to water abstraction, flow modifications and water quality.

Invertebrates: This Upper Foothill site had the highest SASS5 Score and ASPT of the three Upper Foothill sites assessed in the wet season. It was the only Upper Foothill site that was not dry in the dry season, although the water level had dropped significantly as reflected by the drop in taxa, from 17 in the wet season to 12 taxa in the dry season. *Specific biotopes:* SIC included riffle, run and boulder rapid (wet season only), SOOC were in backwaters, slackwaters and pools; MVIC and MVOC were mostly grasses and reeds; and mud occurred in backwaters, slackwaters and pools. Stones were covered in silt in the dry season and the quality of the stones and vegetation biotope was decreased. The marginal vegetation supported the highest number of invertebrate taxa in the wet season. The fauna included crabs, water-mites, mayflies, dragon- and damselflies, bugs, caddisflies, beetles, flies and snails. The limpet, Ancylidae, was only recorded at this site (dry season).

Wet Season

	SASS5 Score	Number of Taxa	ASPT	Taxa recorded
Stones	50	7	7.14	Potamonautidae, Hydracarina, Baetidae >2 Sp, Heptageniidae, Tricorythidae, Coenagrionidae, Aeshnidae, Gomphidae, Belastomatidae, Naucoridae, Hydropsychidae 2 Sp, Leptoceridae, Dytiscidae, Ceratopogonidae, Chironomidae, Simulidae and Thiaridae
Veg	94	15	6.27	
GSM	3	1	3.00	
Combined	105	17	6.18	

Dry Season

	SASS5 Score	Number of Taxa	ASPT	Taxa recorded
Stones	40	7	5.71	Potamonautidae, Baetidae 2 Sp, Caenidae, Heptageniidae, Coenagrionidae, Gomphidae, Vellidae, Hydropsychidae 1 Sp, Ceratopogonidae, Chironomidae, Ancylidae and Planorbidae
Veg	30	7	4.29	
GSM	14	3	4.67	
Combined	60	12	5.00	

Fish: Habitat was largely limited to fast, deep in the wet season, and slow, deep and slow, shallow in the dry season. There was overhanging vegetation, undercut banks, rocky and sandy substrate and water column. Three species of fish were recorded.

Riparian Vegetation: The impact on the riparian vegetation was localized. Downstream of the site the riparian width was 10m on the right hand bank and 10m on the left hand bank. Forty-six species were recorded and trees and shrubs dominated with a few sedges and grasses were present. There was very limited encroachment by exotic vegetation.

R6 - Ruvu River

Zone: Lower Foothill (S03° 31.732'; E37° 33.759', altitude = 713m); at Kifaru, upstream of bridge

The Ruvu River (Figure 3.11 and Figure 3.12) is fed by several rivers, including the Muraini River, which rises in the North Pare Mountains and which flows north through Lake Jipe and surrounding swamps (3500 ha). Downstream of the site the Ruvu River is joined by the rivers flowing off the central and eastern Kilimanjaro, including the Himo, Mue (joined by the Miwaleni) and the Rau (joined by the Njoro). At R6 the river had a straight, single thread channel, with an alluvial channel type, dominated by silt and clay. The reach type was regime. The summarised river make up was a run only in the wet season, becoming was a mix of riffle and run in the dry season.

Wet-season:
Macro-channel width was approx. 100 m, active channel width was 40m and surface water width was 15m. The left and right bank heights were 2m and 1.5m respectively. The deep-water physical biotope was a deep run (average depth = 1.3m) and the shallow-water physical biotope was vegetation-in-current (average depth = 0.3m).

View of site - upstream

View of site - downstream

Marginal vegetation biotope

Water quality sampling

Figure 3.11 R6 – Ruvu River in the wet season

Dry season:
Water levels had dropped since the wet season survey. Surface water width was 12.5m, deep-water physical biotope was a run (average depth = 1.0m) and the shallow-water physical biotope was a gravel/cobble riffle (average depth = 0.3m).

Assessment of river health

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
B/C	D	D	D	D	D	C

Discharge: The river at this site was perennial, although flows were lower in the dry season compared to the wet season, and the dry period was extended beyond the expected dry season. Annual flooding occurs and the low flows are sustained by outflow from Lake Jipe. There was a wetland upstream of the site although information on this was limited. Lake Jipe has experienced a decline in water levels over the last decade.

Water quality: Critically low dissolved oxygen levels during the wet and dry seasons were recorded, most likely caused by extensive decaying material upstream and the fact that it is a low-gradient river downstream of Lake Jipe. Total Phosphorus increased during the dry season. Aquatic macrophytes were recorded in the dry season, indicating that Total Nitrogen was limited (*Azolla pinnata* has nitrogen fixing bacteria associated with it).

Condition of local catchment: The local catchment had a number of developments potentially impacting the river health, including, agricultural crops, livestock, irrigation, alien vegetation infestation, construction, roads, rural development, recreational and litters/debris disposal. Gravel roads in riparian zone upstream were the features contributing to the in-channel and bank modifications albeit limitedly. Downstream, a bridge with side channel supports, and tar and gravel roads in the riparian zone had a limited impact. Water quality, particularly low dissolved oxygen, decrease of indigenous vegetation from the riparian zone and bank erosion were the main contributors to the IHI scores of D - largely modified for instream and riparian zone.


View of site - upstream


View of site - downstream


Aquatic vegetation biotope - *Ceratophyllum demersum*


Azolla pinnata mats on water surface

Figure 3.12 R6 – Ruvu River in the dry season

Invertebrates: This Lower Foothill site only had marginal vegetation and mud for sampling in the wet season, although gravel, pebbles and cobbles provided stones biotope in the dry season. *Specific biotopes:* SIC (dry season only) included riffle and run; SOOC (dry season only) were in a slackwaters; MVIC and MVOC included grasses, reeds and shrubs; AQV (dry season only) was *Ceratophyllum demersum*; and gravel, sand and mud occurred in slackwaters and in channel. In the wet season, the fauna was dominated by air-breathing bugs and the fly, *Chironomus* spp., which is highly tolerant of anoxic conditions. Oligochaetes, damselflies, and the snails, Lymnaeidae and Planorbidae, were recorded in the dry season. Water scorpions, Nepidae, were also recorded in the dry season. Total number of taxa was 16.

Wet Season

	SASS5 Score	Number of Taxa	ASPT	Taxa recorded
Stones	-	-	-	Baetidae 1 Sp, Belastomatidae, Corixidae, Gerridae, Hydrometridae, Naucoridae, Veliidae, Dytiscidae, Gyrinidae and Chironomidae
Veg	37	8	4.63	
GSM	22	6	3.67	
Combined	45	10	4.50	

Dry Season

	SASS5 Score	Number of Taxa	ASPT	Taxa recorded
Stones	2	1	2.00	Oligochaeta, Baetidae 1 Sp, Coenagrionidae, Belastomatidae, Corixidae, Gerridae, Nepidae, Pleidae, Dytiscidae, Chironomidae, Lymnaeidae and Planorbidae
Veg	39	11	3.55	
GSM	7	3	2.33	
Combined	40	12	3.3	

Fish: Habitat was largely limited to fast, deep in the wet season, and slow, deep in the dry season. There was overhanging vegetation (sedges and trees), few undercut banks, macrophytes; rock, gravel and sand substrate and water column. Five species were recorded in the wet season - possibly migrating upstream to the swamp area for spawning. Two additional species were recorded in the dry season. Fish were observed gulping for air, indicating stress resulting from low dissolved oxygen concentrations.

Riparian Vegetation: The riparian width was 10m on the right hand bank and 18m on the left hand bank. Thirty-four species were recorded and trees, shrubs, reeds, sedges and grasses were represented. There was very limited encroachment by exotic vegetation.

R7 - Muraini (Mvuleni) River

Zone: Upper Foothill (S03° 43.794'; E37° 42.472', altitude = 782m); upstream Lake Jipe, above road bridge

The Muraini River (Figure 3.13 and Figure 3.14), rising in the North Pare Mountains and flowing north into Lake Jipe and surrounding swamps (3500 ha), becomes the Ruvu River at its exit from the lake. At R7 the river had a straight, single thread channel, with an alluvial channel type, dominated by cobble. The reach type was pool-riffle. The summarised river make up was a mix of riffle/rapid, run and pool.

Wet-season:

Macro-channel width was approx. 50 m, active channel width was 10m and surface water width was 1m. The left and right bank heights were both 1.5m. The deep-water physical biotope was a pool (average depth = 0.5m) and the shallow-water physical biotope was a cobble riffle (average depth = 0.1m).

Dry season:

The river was dry, although this is not unexpected as it is a naturally seasonal river, which stops flowing in the dry season.

Assessment of river health

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
D	B/C	C	C	B/C	-	A

Discharge: The river at this site was seasonal and it naturally ceased to flow in the dry season. Water abstraction in the wet season was estimated at >60%. It is likely that the dry season was extended beyond the expected dry season because of the abstraction during the wet season. No information was available on floods.

Water quality: Turbidity and Totoal Suspended Solids were higher than expected for an Upper Foothill site - this may be a consequence of the rain that preceded the assessment.

Condition of local catchment: The local catchment had a number of developments incldiung agricultural crops, livestock, alien vegetation infestation, roads, weirs and rural development, although potential impact to river health was limited. Wilderness area was extensive in the catchment. The features impacting the in-channel and bank modifications upstream were weirs while downstream a low-flow bridge, a gravel road in the riparian zone and a small dam were found. The impact of the features was limited. The catchment was classified as moderately modified (class C) for both instream and riparian zone according to the IHI, mainly because of water abstraction, flow modifications and water quality.

View of site - upstream

View of site - downstream

Cobble Riffle

Figure 3.13 R7 – Muraini River in the wet season

Invertebrates: This Upper Foothill site was a very narrow stream and the stones biotope was limited to a small, shallow, cobble riffle. *Specific biotopes:* R7 - SIC included riffle and run; sand and mud occurred in slackwaters (wet season only). No marginal vegetation was available for sampling. Nonetheless a total of 13 taxa were recorded. It was one of two sites in the survey where butterfly larvae, Crambiidae, were recorded, as well as the flies, Athericidae and Tabanidae. The site was dry in the dry season.

Wet Season

	SASS5 Score	Number of Taxa	ASPT	Taxa recorded
Stones	54	10	5.40	Oligochaeta, Potamonautidae, Baetidae 1 Sp, Crambiidae, Hydropsychidae 2 Sp, Dytiscidae, Elmidae, Hydrophilidae, Athericidae, Ceratopogonidae, Chironomidae, Ephydridae and Tabanidae
Veg	-	-	-	
GSM	17	4	4.25	
Combined	69	13	5.31	

Fish: Habitat was limited to slow, shallow pool areas. There was overhanging vegetation, undercut banks in the pool area and gravel substrate. Little cover was provided by the water column. No fish were caught, although they are known to be found downstream in the rainy season.

Riparian Vegetation: The riparian width was 150m on the right hand bank and 200m on the left hand bank. Thirty species were recorded and trees, shrubs and grasses were represented. There was very limited encroachment by exotic vegetation. The riparian vegetation has a closed canopy with minimal undergrowth herbaceous plants. The dominant plants were the fig trees (*Ficus ssp.*) which are adapted to surviving in dry areas due to their ability to reserve/store water.

View of site - upstream

View of site - downstream

Downstream pool area - dry

Figure 3.14 R7 – Muraini River in the dry season

R8 - Pangani River

Zone: Lower Foothill (Swamp) (S04° 10.920'; E37° 30.186', altitude = 632m); at Kirua swamp

The Pangani River at Kirua Swamp (Figure 3.15 and Figure 3.16) is downstream of the Nyumba ya Mungu dam. At R8 the river had a straight, single thread channel, located within a broader floodplain / swamp area. The river resembled that of a mature lower river zone. It had an alluvial channel with silt, clay and sand as the dominant substrata. The reach type was regime. The summarised river make up was a mix of run and pool.

Wet-season:

Macro-channel width was approx. 8000 m (including the floodplain), active channel width was 100m and surface water width was 30m. The left and right bank heights were both 0.3m. The deep-water physical biotope was a pool/deep run (average depth = 1.5m) and the shallow-water physical biotope was a sand/mud backwater (average depth = 0.3m).

Dry season:

Water levels had risen since the wet season survey. Surface water width was 30m, deep-water physical biotope was a pool/deep run (average depth = 1.8m) and the shallow-water physical biotope was a sand/mud backwater (average depth = 0.4m).

View of site - upstream

View of site - downstream

Marginal vegetation biotope - *Typha capensis*

Fishing trap across river upstream

Figure 3.15 R8 – Pangani River in the wet season

Assessment of river health

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
D	C	C	C	C	A/B	B

Discharge: Flow was highly regulated by NYM dam and there was no significant inflow between the dam and the site. Floods were held back at the dam, high flows were irregular and flows were constant. Dry season base flows were higher than wet season base flows. Flooding of Kirua swamps no longer occured. Depth of the river at this site had increased due to trapping of sediment by the dam.

Water quality: Total Phosporus increased in the dry season - causing a shift in trophic status from mesotrophic to eutrophic. The NYM dam upstream is located on calcareous soils - very high levels of carbonates and bicarbonates were released from the dam. The elevated levels continue into the Mature Lower River.

Condition of local catchment: The local catchment had livestock, mainly cattle and goats, which extensively affected the riparian zone both within and beyond, with a moderate potential impact on river health. Wilderness area was also extensive, while rural development was moderate with a limited impact. The in-channel and bank modifications were mainly contributed by gravel roads in the riparian zone and weirs (local fishing wares) upstream, though both had limited impact. The IHI score classified the catchment as moderately modified (class C) for both instream and riparian zone. The modifications included water abstraction, flow modifications, water quality and decrease of indigenous vegetation from the riparian zone. The Nyumba ya Mungu dam was approximately 30 kms upstream of this site.

View of site - upstream

View of site - downstream

Marginal vegetation - grasses inundated by elevated water levels

Fishing trap across river upstream

Marginal vegetation biotope - *Cyperus alticularis*

Figure 3.16 R8 – Pangani River in the dry season

Invertebrates: This Lower Foothill site only had marginal vegetation for sampling. A fish trap positioned across the river upstream of the site provided a fast flowing area for sampling. *Specific biotopes:* MVIC and MVOC included grasses, reeds, shrubs and sedges; sand and mud occurred occurred in backwater, slackwaters and in channel. Fifteen taxa were recorded, with ten taxa recorded in marginal vegetation in the wet season, including mayflies, damselflies, bugs, caddisflies, beetles and flies. The damselfly, Calopterygidae, was recorded for the first time. Hydropsychidae and Simuliidae were recorded in the fish trap in the fast flowing water. Unfortunately logistical reasons prevented the sampling of the fish trap in the dry season. The water levels at this site were higher in the dry season due to releases from NYM.

Wet Season

	SASS5 Score	Number of Taxa	ASPT	Taxa recorded
Stones	-	-	-	Baetidae 2 Sp, Caenidae, Calopterygidae, Belastomatidae, Gerridae, Veliidae, Hydropsychidae 1 Sp, Dytiscidae, Chironomidae and Simuliidae
Veg	51	10	5.10	
GSM	-	-	-	
Combined	51	10	5.10	

Dry Season

	SASS5 Score	Number of Taxa	ASPT	Taxa recorded
Stones	-	-	-	Coenagrionidae, Cordullidae, Belastomatidae, Corixidae, Nepidae, Notonectidae, Veliidae and Dytiscidae.
Veg	34	8	4.25	
GSM	-	-	-	
Combined	34	8	4.25	

Fish: Habitat was limited to fast, deep areas. There was overhanging vegetation, emergent macrophytes, gravel/sand/mud substrate and water column. Ten species of fish were recorded. Migratory fish species were recorded, but their availability and distribution may be affected by the fishing weir upstream.

Riparian Vegetation: The riparian width was 10m on the right hand bank and 15m on the left hand bank. Thirty-four species were recorded and trees, shrubs, reeds, sedges and grasses were all well represented. There was no encroachment by exotic vegetation.

R9 - Pangani River

Zone: Lower Foothill (S05° 03.756'; E38° 07.868', altitude = 480m); at Mkalamo village (approx 500m upstream of bridge at bedrock rapid)

Upstream of R9 (Figure 3.17 and Figure 3.18), the Pangani River is joined by tributaries flowing from the drier western region of the catchment. At R9 the river has a straight, single thread channel, although small vegetated and rocky islands are present within the channel. It has a mixed bedrock and alluvial channel with bedrock and sand the dominant substrata. Pools alternate with bedrock rapid areas making the reach type pool-rapid. The summarised river make up was a mix of riffle/rapid, run and pool.

Wet-season:

Macro-channel width was approx. 50 m, active channel width was 30m and surface water width was 20m. The left and right bank heights were both 1.5m. The deep-water physical biotope was a pool/deep run (average depth = 1.5m) and the shallow-water physical biotope was a bedrock rapid (average depth = 0.3m).

Dry season:

Water levels had risen since the wet season survey. Surface water width was 20m, deep-water physical biotope was a pool/deep run (average depth = 1.8m) and the shallow-water physical biotope was a bedrock rapid (average depth = 0.1m).

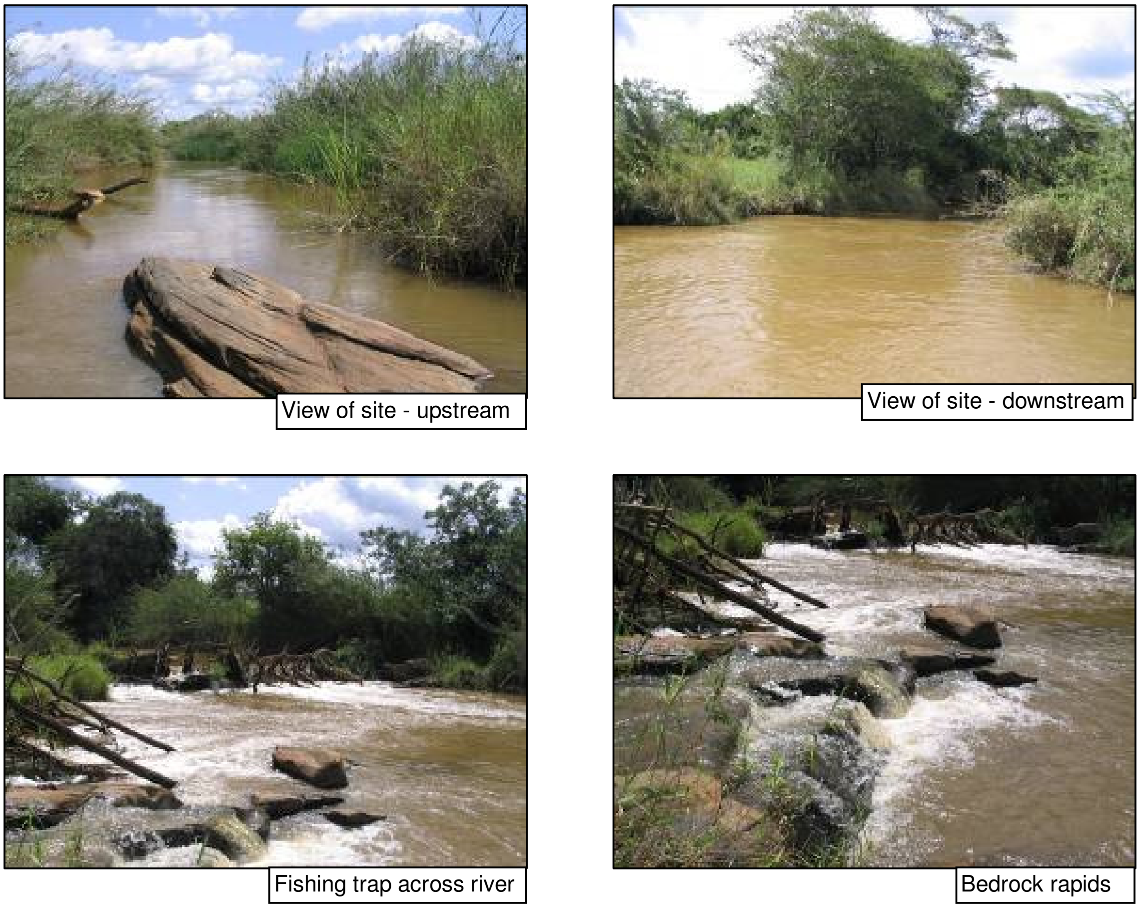


Figure 3.17 R9 – Pangani River in the wet season

Assessment of river health

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
D	C	C	D	B	B	B

Discharge: Flow was regulated by NYM dam and there was no significant inflow between the dam and the site. Floods were held back at the dam, high flows were irregular and flows were constant. Dry season base flows were higher than wet season base flows.

Water quality: Higher nitrogen concentrations and chlorophyll *a* levels in the wet season indicated that the system was modified in terms of water quality. Total Phosporus increased in the dry season causing a shift in trophic status from mesotrophic to eutrophic. Upstream of the site there is extensive sisal plantations, cattle ranches and localized agriculture in the riparian zone.

Condition of local catchment: The local catchment was moderately dominated by agricultural activities, crops and livestock, within and beyond the riparian zone, both with a moderate potential impact on river health. Upstream a weir (local fishing ware) was the only feature contributing to in-channel and bank modifications with a limited impact, while downstream a bridge with side channel supports had limited impact. The catchment was moderately modified (class C) for instream and largely modified for the riparian zone (class D). The main factors contributing to the IHI scores are water abstraction, flow modifications, water quality and decrease of indigenous vegetation.


View of site - upstream


View of site - downstream


Fishing trap across river - indicating higher water levels


Bedrock rapids

Figure 3.18 R9 – Pangani River in the dry season

Invertebrates: This Lower Foothill site had a relatively high SASS5 Score and ASPT for a Lower Foothill site. All three biotopes were sampled, with stones limited to bedrock rapids and cascades. *Specific biotopes:* SIC was all bedrock rapid; SOOC were bedrock; MVIC and MVOC included grasses, reeds and shrubs; and sand occurred in backwaters, slackwaters and in channel. The marginal vegetation supported the highest number of invertebrate taxa. No taxa were recorded in the sand although sampling was difficult due to the risk of crocodiles. The total number of taxa recorded was 17. The fauna included crabs, water-mites, mayflies, butterfly larvae, dragon- and damselflies, bugs, caddisflies, beetles, flies and snails. Of note were the five different types of cased-caddisfly in the family Leptoceridae in the wet season. Fewer taxa were recorded in the stones biotope in the dry season - the water levels were higher due to releases from the NYM dam. This might have been a reflection of the increased difficulty in sampling the stones biotope due to the elevated flow, rather than a true reduction in the number of invertebrates.

Wet Season

	SASS5 Score	Number of Taxa	ASPT	Taxa recorded
Stones	76	10	7.60	Hydracarina, Baetidae >2 Sp, Tricorythidae, Crambiidae, Calopterygidae, Coenagrionidae, Gomphidae, Libellulidae, Corixidae, Naucoridae, Veliidae, Hydropsychidae > 2 Sp, Leptoceridae, Dytiscidae, Chironomidae and Simulidae
Veg	79	12	6.58	
GSM	0	0	0	
Combined	110	16	6.88	

Dry Season

	SASS5 Score	Number of Taxa	ASPT	Taxa recorded
Stones	24	4	6.00	Baetidae >2 Sp, Tricorythidae, Calopterygidae, Coenagrionidae, Libellulidae, Naucoridae, Veliidae, Hydropsychidae 2 Sp, Leptoceridae and and Simulidae
Veg	57	9	6.33	
GSM	0	0	0	
Combined	68	10	6.8	

Fish: Habitat included fast, deep and fast, shallow (bedrock rapids) areas. There was overhanging vegetation, rocky and sandy substrate and water column. Four species of fish were recorded. There is a fishing weir across the river and discussions with local fishermen indicated that seven species have been caught at this site.

Riparian Vegetation: The riparian width was 10m on the right hand bank and 5m on the left hand bank. Thirty-two specied were recorded and trees, shrubs, reeds, sedges and grasses were all represented. There was no encroachment by exotic vegetation.

R10 - Pangani River

Zone: Rejuvenated Bedrock Cascade (S05° 17.910'; E38° 36.271', altitude = 271m); at Mwakinyumbi (downstream of Hale town)

Above this site the Pangani River is joined by the Mkomazi and Luengera Rivers, which drain the South Pare and Usambara Mountains, respectively. After the confluence with the Luengera River, the Pangani River enters the rejuvenated bedrock cascade zone. The storage impoundment for the Hale Hydropower station was upstream of this site. At R10 the river had a straight, multiple thread channel, although the side channel is relatively small compared to the main channel. It had a bedrock channel, with pools alternating with bedrock rapid areas making the reach type pool-rapid. The summarised river make up was a rapid and run.

Wet-season:

Macro-channel width was approx. 100 m, active channel width was 50m and surface water width was 10m. The left and right bank heights were 1m and 0.75m respectively. The deep-water physical biotope was a deep run (average depth = 1m) and the shallow-water physical biotope was a bedrock rapid (average depth = 0.3m).

Dry season:

Water levels had dropped since the wet season survey. Surface water width was 4m, deep-water physical biotope was a pool/run (average depth = 0.5m) and the shallow-water physical biotope was a bedrock rapid (average depth = 0.2m).

Assessment of river health

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
D	D	D	E	D	C/D	D

Discharge: Flow was regulated by NYM dam and there was an additional pool (head pond) for storing water before entering the Hale Hydropower station. There were several rivers joining the Pangani River upstream of this site, which contributed to inflows. Floods seem to have the normal pattern. In the dry seasons, the river below the HEP sometimes dried out due to the entire river water being abstracted to generate HEP.

Water quality: Conductivity, nitrites and TP increased in the dry season. The system shifted from mesotrophic to hypertrophic. DO decreased especially in the slower flowing areas of the river. Bacterial contamination (faecal coliforms) may impact upon human health at this site. Rubbish dumping occurred within the riparian zone.

Figure 3.19 R10 – Pangani River in the wet season

Condition of local catchment: A moderate and extensive rural development within and beyond the riparian zone was the land- use feature in this local catchment, resulting in an extensive potential impact on river health. The urban development mainly beyond the riparian zone was limited. Extensive impoundment within and beyond the riparian zones were however considered to impact moderately. Litter was moderate in both zones with a moderate impact as well. The impoundment weir upstream was considered to extensively contributed to the in-channel and bank modifications while a bridge with in-channel supports and a tar road in riparian zone are considered to have a limited contribution. Downstream a bridge with in-channel supports was also considered to have a limited contribution to the in-channel and bank modifications. Water abstraction for hydropower generation, flow modifications especially during low flows, water quality, inundation, presence of solid waste, decrease of indigenous vegetation from the riparian zone and exotic vegetation encroachment were the main factors leading to the classes of largely modified and seriously modified for IHI instream (class D) and riparian zone (class E) respectively.

Invertebrates: This Rejuvenated bedrock cascade site had stones (limited to bedrock) and vegetation available for sampling. *Specific biotopes:* SIC were all bedrock rapid; SOOC were bedrock; MVIC and MVOC included grasses; sand and mud occurred in backwaters and slackwaters. More taxa were recorded in the dry season (19 taxa) compared to the wet season (13 taxa), although most of them were ones that are able to tolerate reduced water quality (e.g. Oligochaete, Corixidae, Notonectidae). Three taxa were recorded in the stones in the wet season, including leeches (Hirudinea), while 12 taxa were recorded in stones in the dry season. Small cobble areas were available for sampling during the dry season due to the lower water levels and discharge. This was only one of two sites in the survey where leeches were found. The marginal vegetation supported the highest number of invertebrate taxa, including dragon- and damselflies, bugs, flies and snails. The total number of taxa recorded was 22.

View of site - upstream

View of site - downstream

Marginal vegetation no longer in contact with the water

Rubbish dumping within the riparian zone

Recreational and domestic use of the river

Figure 3.20 R10 – Pangani River in the dry season

Wet Season

	SASS5 Score	Number of Taxa	ASPT	Taxa recorded
Stones	12	3	4.00	Hirudinea, Potamonautidae, Baetidae 2 Sp, Calopterygidae, Coenagrionidae, Libellulidae, Belastomatidae, Naucoridae, Veliidae, Hydropsychidae 1 Sp, Chironomidae, Thiaridae and Viviparidae
Veg	57	13	4.38	
GSM	-	-	-	
Combined	59	13	4.54	

Dry Season

	SASS5 Score	Number of Taxa	ASPT	Taxa recorded
Stones	52	12	4.33	Oligochaete, Hirudinea, Potamonautidae, Baetidae 2 Sp, Caenidae, Coenagrionidae, Gomphidae, Libellulidae, Corixidae, Naucoridae, Notonectidae, Veliidae, Hydropsychidae 1 Sp, Gyrinidae, Chironomidae, Simuliidae, Tabanidae, Lymnaeidae and Viviparidae
Veg	51	14	3.64	
GSM	-	-	-	
Combined	80	19	4.21	

Fish: Habitat included fast, deep and fast, shallow (bedrock rapids) areas in the wet season, but changed to slow, shallow areas in the dry season. There was sparse undercut banks, rocky substrate and water column (decrease from wet to dry season). Ten species of fish were recorded in the wet season, but no fish were recorded in the dry season. This may be a reflection of the reduction in water quality and quantity (backwater habitat not available in the dry season), although problems with the electroshocker may also have contributed to this.

Riparian Vegetation: The riparian width was 5m on the right hand bank and 5m on the left hand bank. Seventeen species were recorded and trees, shrubs, sedges and grasses were represented. There was limited encroachment by exotic vegetation. The riparian vegetation is severely exploited and the impact from rural development vegetation is high.

R11 - Pangani River

Zone: Mature Lowland River (S05^{o} 21.850'; E38^{o} 14.175', altitude = 20m); at Jambe village, approx. 500m downstream of outflow from Pangani Falls Hydropower Station

This site on the Pangani River was below the point at which the outflow from the Pangani Falls Hydropower Station joins the river (Figure 3.21 and Figure 3.22). At R11 the river had a straight, single thread channel, with an alluvial channel. The dominant substratum was sand and the reach type was regime. The summarised river make up was run.

Wet-season:

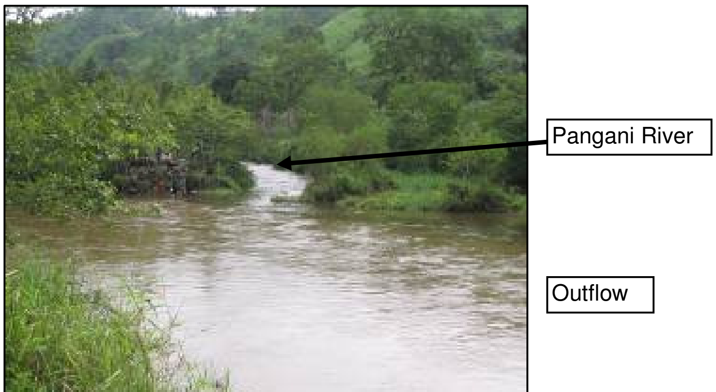
Macro-channel width was approx. 100 m, active channel width was 70m and surface water width was 60m. The left and right bank heights were 1m and 2m respectively. The deep-water physical biotope is a pool/deep run (average depth = 2m) and there is no shallow-water physical biotope.

Dry season:

During the sampling period, water levels had dropped since the wet season. Discussions with local fisherman indicate that for approximately 8 hours within every 24 hours, the river below the Pangani Falls Hydropower Station ceased to flow. Water becomes limited to isolated pools, with a small amount of water flowing from the Pangani River that is not diverted into the hydropower station. Surface water width was 50m, deep-water physical biotope was a pool/run (average depth = 0.75m) and the shallow-water physical biotope was a gravel slackwater (average depth = 0.15m).

View of site - upstream

View of site - downstream



Confluence of Pangani River and outflow from hydropower station

Figure 3.21 R11 – Pangani River in the wet season

Assessment of river health

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
D	C	D	E	C	C	B

Discharge: Flow was regulated by NYM dam and there are two additional pools (head ponds) for storing water before entering the Pangani Falls Hydropower station. There were several rivers joining the Pangani River upstream of this site, which contributed to inflows. Flows below the intake depend on releases from the HEP and were intermittent in the dry season. The river below dried up for approximately 8 hours in every 24 hours. The natural Pangani River sometimes dried out in the dry season due to abstraction for HP.

Water quality: Turbidity was elevated below the HEP station due to releases from the station. Nitrite increased in the dry season. The sub-site R11A, which was on the natural river above the confluence with the outflow, had higher TP in the dry season, which caused a shift in trophic status from mesotrophic to hypertrophic.

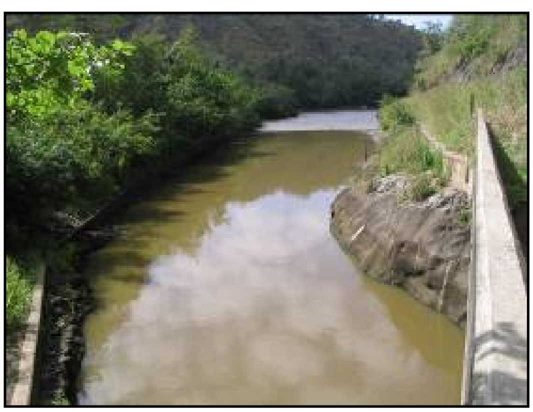
Condition of local catchment: Impoundments for hydropower generation within and beyond the riparian zones were the major features considered extensive in terms of land use within and beyond the riparian zone resulting in an extensive potential impact on the river health. The wilderness area was extensive in the riparian zone and moderate beyond the same. The impoundment/dams and canalization of the bank upstream were the main factors contributing to the in-channel and bank modifications with extensive and limited impacts respectively. The IHI score indicated that the local catchment was largely and seriously modified for instream (class D) and riparian zone (class E) respectively. Water abstraction for hydropower generation, flow modifications, water quality and extent of inundation were the major contributors to the score.

View of site - upstream

View of site - downstream

Marginal vegetation

Gravel in slackwater



River immediately below outlet from Pangani Hydropower Station

Figure 3.22 R11 – Pangani River in the dry season

Invertebrates: This Mature Lowland River only had vegetation available for sampling in the wet season. In the dry season, gravel/sand was also sampled. *Specific biotopes:* MVIC and MVOC included grasses, reeds and shrubs; gravel and sand occurred in slackwaters and in-channel (dry season only). Three taxa were recorded in the wet season, including the shrimp (Atyidae). More taxa (6) were recorded in the dry season, although these included highly tolerant worms, Oligochaete, air-breathing Corixidae, Notonectidae and Dytiscidae. Atyidae were also recorded at R11A, but at no other sites in the survey. Prawns were recorded at R11A, on the natural river upstream of the confluence with outflow.

Wet Season

	SASS5 Score	Number of Taxa	ASPT	Taxa recorded
Stones	-	-	-	Atyidae, Belastomatidae, Veliidae
Veg	16	3	5.33	
GSM	-	-	-	
Combined	16	3	5.33	

Dry Season

	SASS5 Score	Number of Taxa	ASPT	Taxa recorded
Stones	-	-	-	Oligochaete, Atyidae, Corixidae, Notonectidae, Veliidae, Dytiscidae
Veg	16	3	5.33	
GSM	9	3	3.00	
Combined	25	6	4.17	

Fish: Habitat included fast, deep areas in the wet season. In the dry season, habitat was severely compromised through the drying up of the river. There was overhanging vegetation (trees), macrophytes, substrate (gravel) and water column in wet season. Seven species of fish were recorded in the wet season, but no fish were recorded in the dry season. Some of these were estuarine species. Site R11A also had bedrock and overhanging vegetation was shrubs. Three species of fish were caught at R11A in the dry season, including an eel, which is a migratory species that matures in the river and then migrates to the ocean to spawn.

Riparian Vegetation: The riparian width was 70m on the right hand bank and 5m on the left hand bank. Thirty-three species were recorded and trees, shrubs, sedges and grasses were represented. There was limited encroachment by exotic vegetation.

R11A - Pangani River

Zone: Lower Foothill (S05° 21.689'; E38° 40.156', altitude = 20m); at Jambe village, 50 m above confluence with outflow from the Pangani Falls Hydropower Station

This sub-site on the Pangani River was above the confluence of the point at which the outflow from the Pangani Falls Hydropower Station joins the river. It was added so that stones biotopes, as bedrock rapid, could be sampled. At R11A the river had a straight, single thread channel, with a bedrock channel. The reach type was pool-rapid. The summarised river make up was a mix of riffle/rapid, run and pool.

Wet-season:
Macro-channel width was approx. 100 m, active channel width was 50m and surface water width was 10m. The left and right bank heights were 1m and 3m respectively. The deep-water physical biotope was a deep run (average depth = 0.6m) and the shallow-water physical biotope was a bedrock rapid (average depth = 0.2m).

Dry season:
Water levels had dropped since the wet season survey. Surface water width was 4m, deep-water physical biotope was a run (average depth = 0.3m) and the shallow-water physical biotope was a bedrock rapid (average depth = 0.1m).


View of site - upstream


View of site - downstream


Marginal vegetation

Figure 3.23 R11A – Pangani River in the wet season

Invertebrates: This Lower Foothill site had stones - bedrock with limited, small cobble - and vegetation available for sampling. *Specific biotopes:* SIC were all bedrock rapid; SOOC were bedrock; MVIC and MVOC included grasses, reeds and shrubs; and gravel and sand occurred in slackwaters and in channel. Six taxa were recorded in the wet season, including shrimps, mayflies, damsel- and dragonflies, flies and snails. More taxa (11) were recorded in the dry season, including prawns, air-breathing bugs and mosquito larvae.

Wet season

	SASS5 Score	Number of Taxa	ASPT	Taxa recorded
Stones	26	6	4.33	Atyidae, Baetidae 1 Sp, Coenagrionidae, Libellulidae, Chironomidae, Thiaridae and Viviparidae
Veg	20	4	5.00	
GSM	-	-	-	
Combined	30	7	4.29	

Dry season

	SASS5 Score	Number of Taxa	ASPT	Taxa recorded
Stones	27	5	5.40	Atyidae, Palaemonidae, Baetidae 2 Sp, Caenidae, Libellulidae, Hydrometridae, Naucoridae, Notonectidae, Veliidae, Hydropsychidae 1 Sp, Dytiscidae, Chironomidae, Culicidae and Thiaridae
Veg	68	13	5.23	
GSM	-	-	-	
Combined	70	14	5.00	

View of site - upstream

View of site - downstream

Algae covering bedrock

Figure 3.24 R11A – Pangani River in the dry season

R12 - Mkomazi River

Zone: Lower Foothill (S04° 34.541'; E38° 04.107', altitude = 477m); at Bendera, downstream of Kalimawe Dam

The Mkomazi River (Figure 3.25 and Figure 3.26) drains the South Pare Mountains. The Kalimawe Dam is situated half-way downs its length. At R12 the river had a straight, single thread channel, located within a broader floodplain area. It had an alluvial channel with sand as the dominant substratum. The reach type is regime. The summarised river make up was run.

Wet-season:

Macro-channel width was approx. 1000 m, active channel width was 20m and surface water width was 8m. The left and right bank heights were 0.5m and 0.25m respectively. The deep-water physical biotope was a run (average depth = 0.5m) and the shallow-water physical biotope was a sandy slackwater (average depth = 0.1m).

Dry season:
Water levels had dropped since the wet season survey. Surface water width was 6m, deep-water physical biotope was a run (average depth = 0.4m) and the shallow-water physical biotope was a sandy slackwater (average depth = 0.1m).

Figure 3.25 R12 – Mkomazi River in the wet season

Assessment of river health

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
D	C/D	D	F	C/D	C/D	D

Discharge: Dry season flows were extended beyond the expected dry season and the river was likely to dry up at the end of the dry season. Floods occur but the size has been reduced due to the presence of the Kalimawe Dam upstream. The floodplain was not inundated to extent that it used to be in the past.

Water quality: Conductivity and sulphate concentration were high in the wet and dry season. Conductivity, sulphate and TP increased in the dry season and trophic status changed from mesotrophic to eutrophic. DO decreased in the dry season. There was extensive agriculture upstream of the site including sisal production and maize and the entire floodplain is cultivated.

Condition of local catchment: Extensive cultivation of crops like maize, coconut, beans and rice, within and beyond the riparian zone in the local catchment, resulted in an extensive potential impact on river health. Return flows from irrigation, rural development and recreational activities, also within and beyond the riparian zones were limited in the catchment, with limited impacts as well. No features were found to contribute to the in-channel and bank modifications. Water abstraction, flow modifications, water quality and decrease of indigenous vegetation from the riparian zone were the major developments contributing to the catchment being classified was largely modified (class D) and critically modified (class F) for instream and riparian zone respectively.

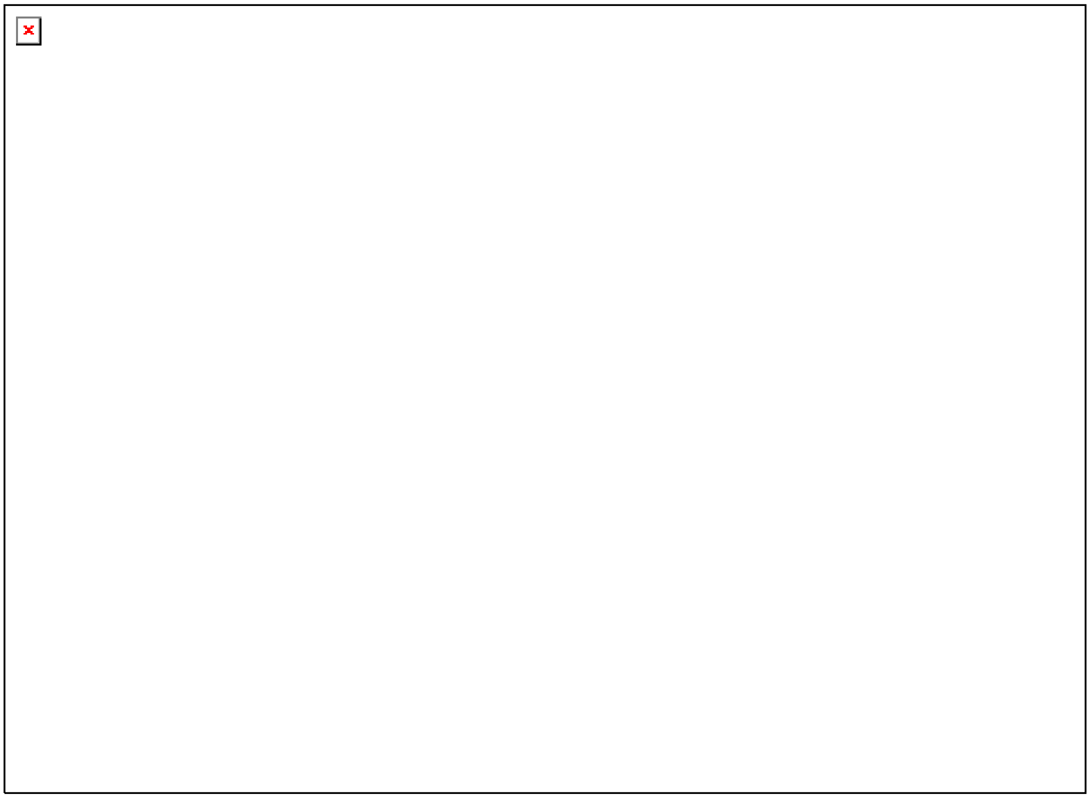


Figure 3.26 R12 – Mkomazi River in the dry season

Invertebrates: This Lower Foothill site had vegetation and mud available for sampling. *Specific biotopes:* MVIC and MVOC included grasses, reeds and shrubs; gravel, sand and mud occurred in backwaters, slackwaters and in channel. A total of 17 taxa were recorded: nine in the wet season and 14 in the dry season, although most of them are relatively tolerant ones. Taxa including worms, mayflies, damsel- and dragonflies, caddisflies, beetles, flies and snails.

Wet Season

	SASS5 Score	Number of Taxa	ASPT	Taxa recorded
Stones	-	-	-	Baetidae 2 Sp, Coenagrionidae, Gomphidae, Belastomatidae, Veliidae, Chironomidae, Ampullaridae, Thiaridae and Viviparidae
Veg	31	8	3.88	
GSM	8	2	4.00	
Combined	37	9	4.11	

Dry Season

	SASS5 Score	Number of Taxa	ASPT	Taxa recorded
Stones	-	-	-	Oligochaete, Baetidae 2 Sp, Caenidae, Calopterygidae, Coenagrionidae, Gomphidae, Libellulidae, Belastomatidae, Hydropsychidae 1 Sp, Dytiscidae, Gyrinidae, Chironomidae, Simuliidae and Thiaridae
Veg	63	13	4.85	
GSM	28	7	4.00	
Combined	64	14	4.57	

Fish: Habitat was largely slow, shallow areas. There was overhanging vegetation (reeds, shrubs), gravel and sand substrate and water column was limited. Overhanging vegetation provides important habitat at this site. Seven species of fish were recorded: six in the wet and one in the dry season. *Clarius gariepinus* (air-breathers) were present - they are tolerant of harsh conditions such as extremely low flows (and drying up).

Riparian Vegetation: The riparian width was 45m on the right hand bank and 105m on the left hand bank. Nineteen species were recorded and reeds and sedges dominated. There is extensive encroachment by exotic vegetation, in addition to some terrestrial plants.

R13 - Luengera River

Zone: Lower Foothill (S05° 08.083'; E38° 30.610', altitude = 296m); at Kwamndolwa, old Korogwe

The Luengera River drains the Usambara Mountains. At R13 the river had a straight, single thread channel, located within a broader floodplain area. Several wetland areas were associated with the river and its floodplain. It had an alluvial channel with sand as the dominant substratum. The reach type was regime. The summarised river make up was pool.

Wet-season:

Macro-channel width was approx. 1000 m, active channel width was 50m and surface water width was 20m. The left and right bank heights were 0.5m and 1.5m respectively. The deep-water physical biotope was a pool (average depth = 2.0m) and the shallow-water physical biotope was a sandy backwater (average depth = 0.1m).

Dry season:

Water levels had dropped since the wet season survey. Surface water width was 13m, deep-water physical biotope was a pool (average depth = 1.0m) and the shallow-water physical biotope was a mud slackwater (average depth = 0.1m).

Assessment of river health

Discharge	Water Quality	IHI In stream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
C	C	C	C	C/D	C	B

Discharge: Dry season flows were extended beyond the expected dry season (due to water abstraction for agriculture) and the river dried up in 2004. Floods occur but the size has been reduced in the past 15 years. There was an extensive floodplain area that still appears to flood annually - wetlands were filled with water in the adjacent floodplain.

Water quality: TN was high in the wet season, possibly as a result of agriculture (sisal, maize, rice) in the surrounding area. TP increased in the dry season and trophic status changed from mesotrophic to eutrophic.

Condition of local catchment: Cultivation of crops like rice, maize and beans in the local catchment was extensive beyond the riparian zone and limited within, with a moderate potential impact on river health. Livestock and rural development were limited, within and beyond the riparian zone, with limited impact, while wilderness area was also limited within and beyond the same. A bridge with in-channel supports and a gravel road in the riparian zone downstream were the features causing the in-channel and bank modifications, although impact was limited. Water abstraction, flow modification, water quality and decrease of indigenous vegetation from the riparian zone mainly contributed to the classification of moderately modified for both instream and riparian zone (class C).

View of site - from downstream road bridge

View downstream from road bridge

View of river and associated wetland areas - floodplain

Associated wetland areas - floodplain

Figure 3.27 R13 – Luengera River in the wet season

View of site - from downstream road bridge

View downstream from road bridge

View of river and associated floodplain

Associated wetland areas - dry

Exposed bank at low flows

Figure 3.28 R13 – Luengera River in the dry season

Invertebrates: This Lower Foothill site had vegetation and mud available for sampling. *Specific biotopes:* R13 - MVIC and MVOC included grasses reeds and shrubs (most was MVOC); sand and mud in occurred backwaters, slackwaters and in channel. This site had a relatively high SASS5 Score and ASPT in the wet season compared to other Lower Foothill sites that only had vegetation and mud for sampling. A total of 18 taxa were recorded: 13 in the wet season, including crabs, mayflies, damsel- and dragonflies, bugs, caddisflies, beetles and snails. Fewer taxa were recorded in the dry season and scores were lower. Leeches were recorded in the dry season.

Wet Season

	SASS5 Score	Number of Taxa	ASPT	Taxa recorded
Stones	-	-	-	Potamonautidae, Baetidae 2 Sp, Coenagrionidae,

Veg	54	11	4.91	Aeschnidae, Corduliidae, Libellulidae, Belastomatidae, Notonectidae, Veliidae, Leptoceridae, Dytiscidae, Gyrinidae and Viviparidae
GSM	15	3	5.00	
Combined	65	13	5.00	

Dry Season

	SASS5 Score	Number of Taxa	ASPT	Taxa recorded
Stones	-	-	-	Hirudinea, Belastomatidae, Corixidae, Hydrometridae, Naucoridae, Veliidae, Dytiscidae, Gyrinidae, Hydrophilidae, Thiaridae and Viviparidae
Veg	50	11	4.55	
GSM	13	3	4.33	
Combined	50	11	4.55	

Fish: Habitat was largely slow, shallow areas. There was overhanging vegetation (reeds and trees), mud substrate and water column. Five species of fish were recorded. Local fishermen indicated that an additional three species were recorded in this site.

Riparian Vegetation: The riparian zone was divided into riparian and floodplain, with widths 2, 120m on the right hand bank and 5, 100 on the left hand bank for riparian and floodplain respectively. Forty species were recorded and trees, shrubs, reeds, sedges and grasses were represented. There was no encroachment by exotic vegetation, reeds or terrestrial plants.

3.2 General trends and analyses

Condition of local catchment

The results discussed in this section include aspects related to the condition of local catchment, land-use, channel condition and index of habitat integrity (IHI). Sites are arranged in the order that they occur down the catchment. Figure 3.29 summarises the land-use within and beyond the riparian zone, and the potential impact of each on the river health at each site. The rates and impact rate are derived from the **rating scale** used to assess the extent of the land-use or impact at each site. The rate refers to the extent to which a land-use is present within and beyond the riparian zone, while an impact rate refers to the potential impact on river health.

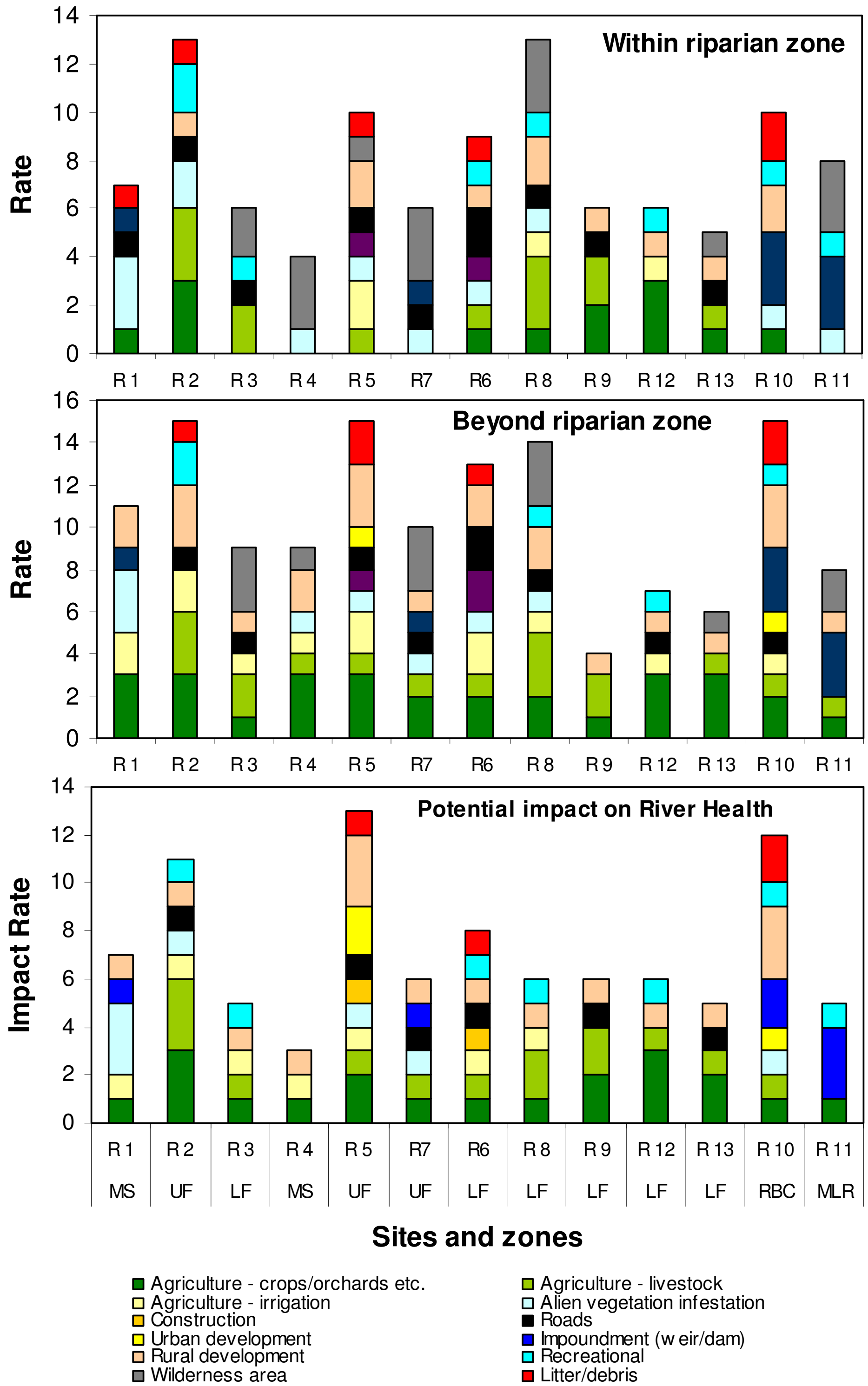


Figure 3.29 Land-use within and beyond the riparian zone, and potential impact on river health at each site. Zones are indicated. This figure summarises the land-use within and beyond the riparian zone, and the potential impact of each on the river health at each site.

The rates of all land-uses identified at a site are summed to generate an overall land-use rate, which is given graphically in Figure 3.29. Twelve land-uses were identified within the Pangani Basin. Sites R2 and R8 had the highest rates within the riparian zone, sites R2, R5, R8 and R10 had the higest rates beyond the riparian zone. The potential impact of land-use on river health was greatest at R5 followed by R10 and R2.

In-channel and bed modifications upstream of each site were greatest at R10 and R11, both of which are immediately below the Hale and Pangani HEP, respectively (Figure 3.30). Eight in-channel and bank modifications were identified in the Pangani Basin.

The higher the instream IHI or riparian IHI the greater the integrity of the instream and riparian habitat (Figure 3.31). For instream IHI, Sites R1 and R4 were both a B (i.e. largely natural), sites R7, R8, R9 and R13 were a C (i.e. moderately modified), while the remaining sites were a D (i.e. largely modified). For riparian IHI, Sites R4, R5, R7, R8 and R13 were a C (i.e. moderately modified), R6 and R9 were a D (i.e. largely modified), R3, R10 and R11 were an E (i.e. seriously modified), while R1, R2 and R12 were an F (i.e. critically modified).

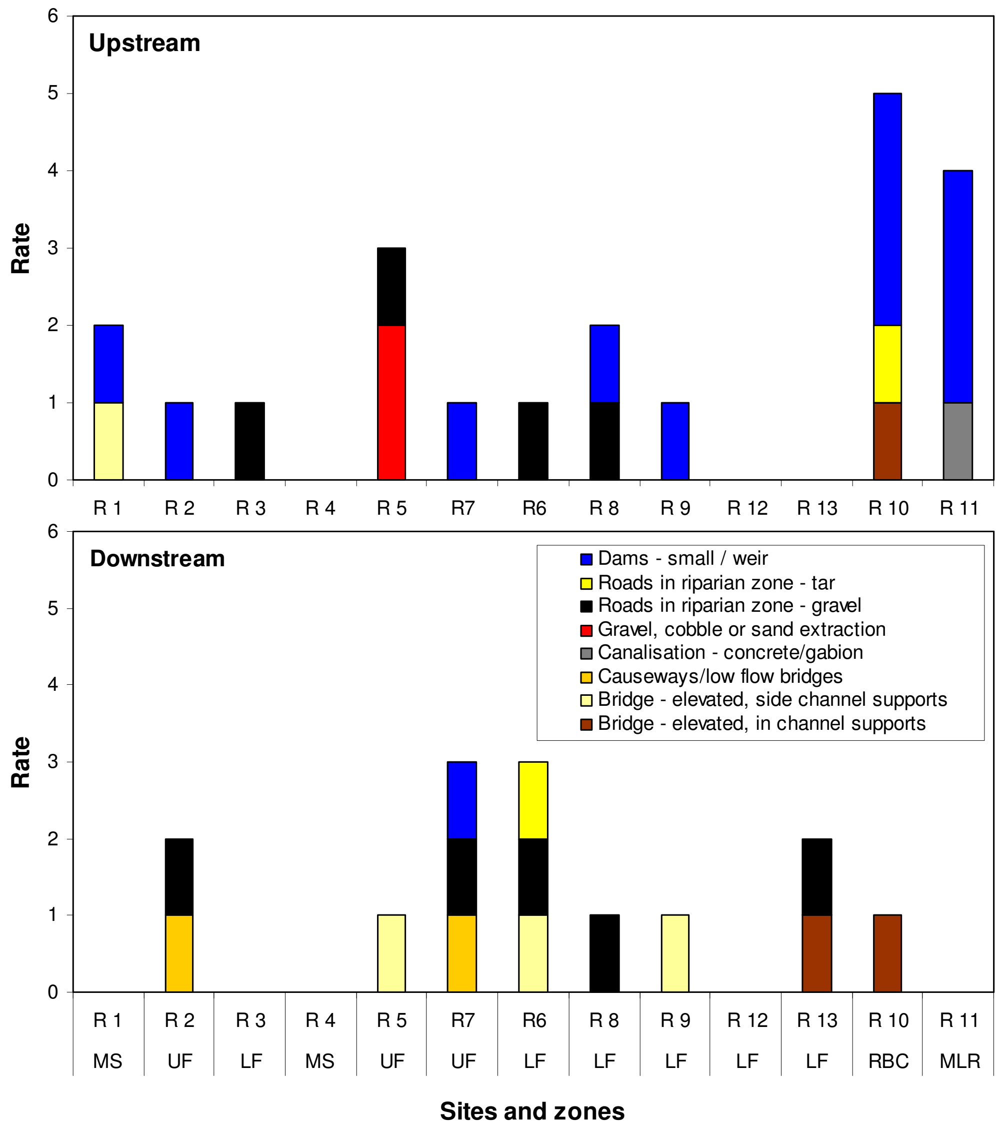
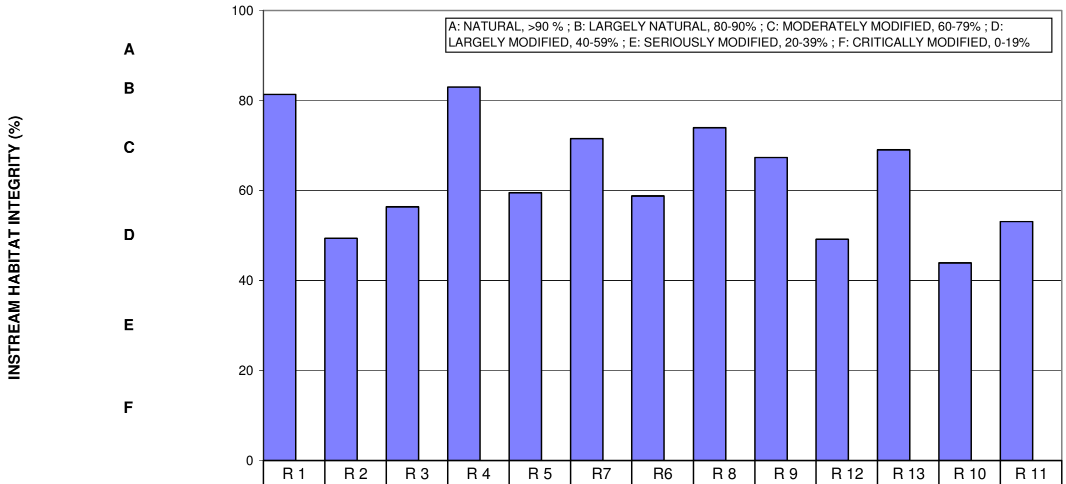
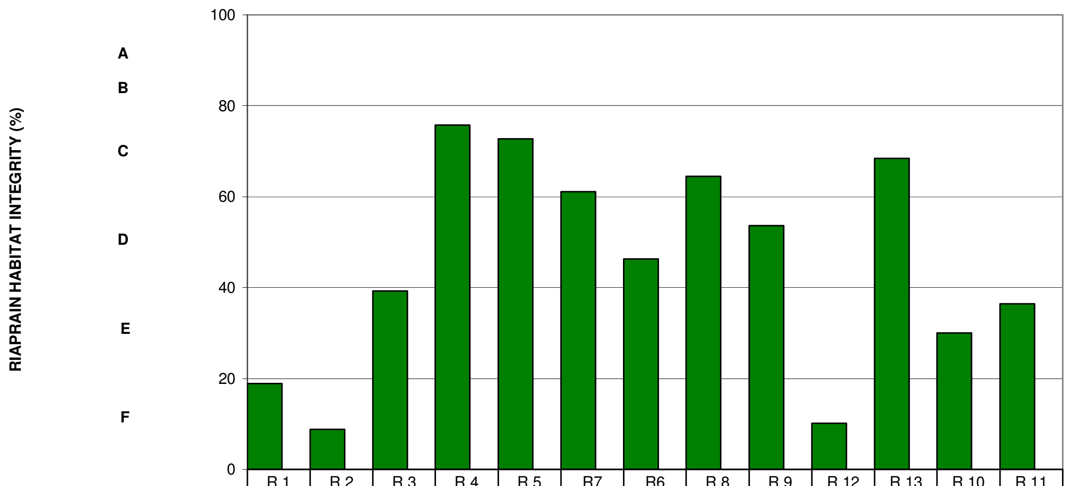


Figure 3.30 In-channel and bed modifications upstream and downstream of each site. Zones are indicated.



	R 1	R 2	R 3	R 4	R 5	R7	R6	R 8	R 9	R 12	R 13	R 10	R 11
INSTREAM HABITAT INTEGRITY SCORE	81	49	56	83	59	72	59	74	67	49	69	44	53
WATER ABSTRACTION	11	25	22	14	15	15	13	10	13	25	13	23	18
FLOW MODIFICATION	9	17	17	5	6	11	6	18	17	20	10	15	18
BED MODIFICATION	0	10	0	0	8	0	0	0	0	0	0	0	0
CHANNEL MODIFICATION	2	2	0	1	0	0	4	0	0	0	3	0	0
WATER QUALITY	3	10	10	3	20	10	24	6	10	13	13	20	10
INUNDATION	2	2	0	0	0	2	2	1	0	0	5	8	15
EXOTIC MACROPHYTES	0	0	0	0	0	0	6	0	0	0	0	0	0
EXOTIC FAUNA	0	0	0	0	0	0	0	0	0	0	0	0	0
SOLID WASTE DISPOSAL	0	1	0	0	11	0	2	0	0	0	0	11	0



	R 1	R 2	R 3	R 4	R 5	R7	R6	R 8	R 9	R 12	R 13	R 10	R 11
RIPARIAN ZONE HABITAT INTEGRITY	19	9	39	76	73	61	46	65	54	10	68	30	36
VEGETATION DECREASE	21	19	10	0	2	0	10	5	8	25	7	23	3
EXOTIC VEGETATION	21	6	0	6	2	0	2	0	1	0	4	8	1
BANK EROSION	10	19	5	0	3	6	10	3	1	6	1	5	0
CHANNEL MODIFICATION	11	2	0	1	0	0	4	0	0	0	3	0	0
WATER ABSTRACTION	11	25	22	14	15	15	13	10	13	25	10	15	18
INUNDATION	2	2	0	0	0	2	0	1	0	0	0	8	15
FLOW MODIFICATION	9	17	17	5	6	11	6	18	17	20	8	15	18
WATER QUALITY	3	10	10	3	6	10	20	6	8	13	13	10	10

Figure 3.31 Instream and riparian habitat integrity at each site. The impact scores for each criterion are given in the associated data table. (See Dallas (2007) for details). Classes are indicated.

Substratum composition

The substratum composition varied amongst the different sites (Figure 3.32). For the bed, a greater abundance of hard substrate, including bedrock, boulder, cobble and pebble, was present at sites in the upper river zones (mountain stream and upper foothill), while more soft substrate, including gravel, sand and mud was present at sites in the lower river zones (lower foothill and mature lowland river). Bedrock was relatively common at three sites, R9, R10 and R11A, which were in the lower foothill and rejuvenated bedrock cascade zones. For the bank, soft substrate, especially sand and mud were abundant at most sites. At site R4 (Ona R.) the river banks consisted on bedrock, while at R9, R10 and R11 bedrock was mixed with sand.

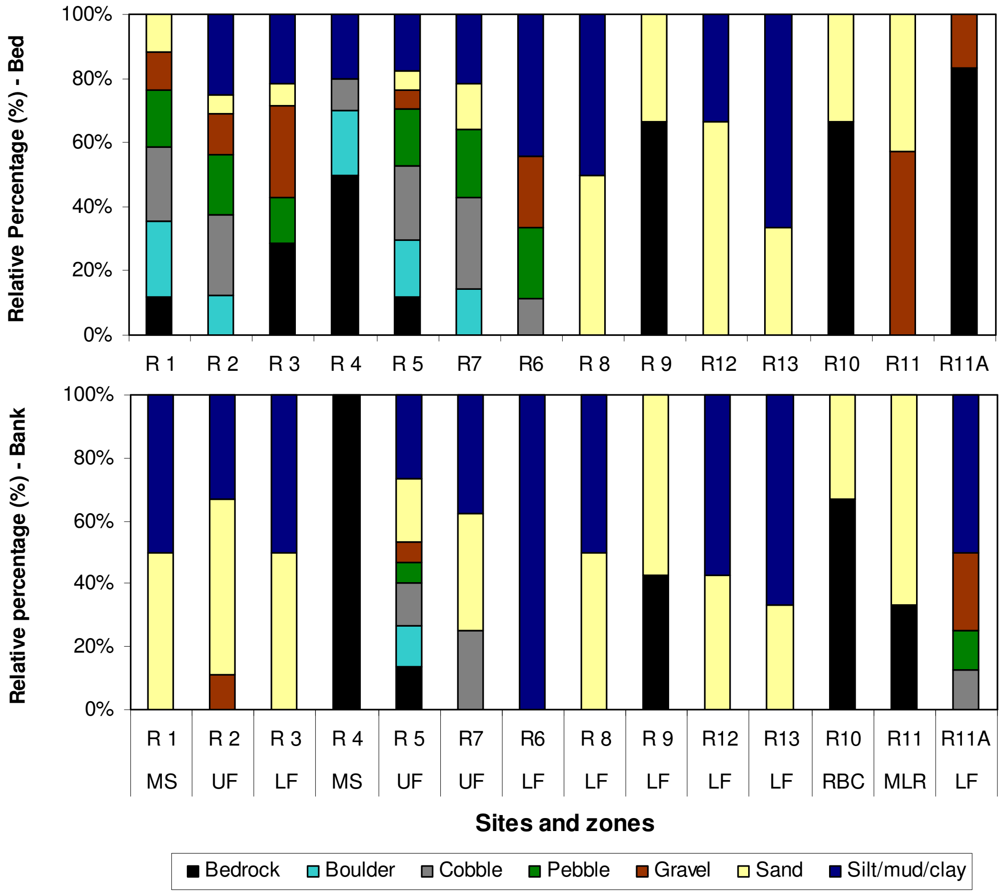


Figure 3.32 Relative percentage of each substrate type for the bed and bank. These percentages are based on the rating scales used to rate the abundance of each substrate.

Water quantity (flow) and quality (water chemistry)

Velocity and discharge

Discharge is given for each site, together with an estimate of the extent of water abstraction for the river upstream until the next site (Table 3.1). **Note:** this is thus not for the entire river system upstream. Generally discharge was lower in the dry season, with the exception of R8, R9, which were regulated by NYM dam. Discharge at R11 in the dry season was highly variable, due to intermittent releases of water from Pangani Falls Hydropower station.

Table 3.1 Discharge calculated during the survey or estimated from rating curves and releases. An estimate of the extent of water abstracted is given.

	Estimate of the extent of water abstracted					
	Wet-season			Dry-season		
Site	**Discharge (m^3s^{-1})**	**% Abstracted**	**Comment**	**Discharge (m^3s^{-1})**	**% Abstracted**	**Comment**
R1	1.32	<40%	Moderate	0.33	>80	Very High
R2	0.92	<30%	Moderate	0	100%	Very High
R3	2.29	<30%	Moderate	0.25	>80	Very High
R4	0.90	<20%	Low	0.58	>60	High
R5	1.043	<20%	Low	0.12	>80	Very High
R6	6.73	<20%	Low	2.89	>60	High
R7	0.003	>60%	High	0	Seasonal river	
R8	12.00*	<10%	Low	18.87*	<40	Moderate
R9	10.00*	<10%	Low	12.87*	<50	Moderate
R10	3.12*	>80%	Very High	0.94*	>90	Very High
R11	19.95*	#	#	14.50*	#	#
R12	0.32	>60%	High	0.16	>90	Very High
R13	5.88*	<20%	Low	2.58*	>60	High

* Discharge figures estimated from rating curves and release for diversion for hydropower generation
# No abstraction occurs below the hydropower station.

Table 3.2 Velocity - V (ms^{-1}) and depth - D (m) spot measurements in selected biotopes at various sites during the wet and dry seasons. Biotopes: cobble riffle (CR), Edge rapid (ER), Snag (S), Gravel (G), Gravel/Boulder rapid/riffle (GBR), Boulder rapid/riffle (BR), run-vegetation (RV), Gravel Run (GRu), Bedrock rapid (BeR)

Season	Site	Biotope	D	V	D	V	D	V	D	V	D	V	Avg D (m)	Avg V (ms^{-1})
Wet	**R2**	CR	0.5	0.8	0.34	0.45	0.45	0.98	0.22	0.85	0.16	0.93	0.33	0.80
Wet	**R3**	ER	0.76	0.85	0.58	0.94	0.76	0.94	0.56	0.72	0.52	0.58	0.64	0.81
Wet	**R3**	S	0.44	0.32	0.48	0.34	0.44	0.44	0.42	0.4	0.38	0.38	0.43	0.38
Wet	**R3**	G	0.18	0.62	0.14	0.6	0.1	0.42	0.1	0.37			0.13	0.50
Dry	**R3**	GBR	0.10	0.50	0.12	0.74	0.20	1.04	0.20	0.86	0.20	1.31	0.16	0.89
Wet	**R5**	BR	0.4	0.89	0.42	1.16	0.33	0.53	0.32	0.68	0.21	0.61	0.34	0.77
Dry	**R5**	CR	0.12	0.52	0.08	0.32	0.12	0.55	0.20	0.32	0.18	0.30	0.14	0.40
Wet	**R6**	RV	0.42	0.56	0.12	0.22	0.52	0.44	0.28	0.8	0.1	0.02	0.29	0.41
Dry	**R6**	GRu	0.32	0.96	0.86	0.74	0.43	0.82	0.25	0.96	0.09	0.26	0.39	0.75
Dry	**R6**	RV	0.66	0.18	0.98	0.39	0.82	0.39	0.96	0.11	0.90	0	0.87	0.27
Wet	**R7**	CR	0.03	0.12	0.05	0.2	0.05	0.13	0.05	0.04	0.08	0.13	0.05	0.12
Wet	**R9**	BeR	0.14	0.27	0.12	0.91	0.12	1.13	0.3	0.75	0.32	0.51	0.20	0.71
Wet	**R10**	BeR	0.12	0.37	0.2	0.38	0.5	0.09	0.46	1.03	0.44	0.39	0.31	0.49
Dry	**R10**	BeR	0.13	0.24	0.33	0.06	0.16	1.05	0.40	0.45	0.38	0.86	0.28	0.53
Wet	**R11A**	BeR	0.1	0.34	0.22	1.29	0.42	0.9	0.46	0.2	0.22	0.78	0.31	0.74
Dry	**R11A**	BeR	0.08	0.70	0.10	0.18	0.06	0.51	0.10	0.13	0.08	0.47	0.08	0.40

Physico-chemical parameters

The physico-chemical parameters measured during the wet and dry seasons at each site are provided in Table 3.3. They have been divided into physical, chemical and biological parameters. Further information on water quality in the Pangani River Basin has been summarized in Appendix G. This is based on monitoring data provided by the PBWO.

Physical parameters

Water Temperature

Water temperature varied from 18.3 °C in the Mountain Stream zone to 25.4 °C in the Mature Lower River in the wet season and 16.7 °C to 26.4 °C in the dry season. Note that spot measurements are not very useful measures of temperature as water temperature is highly correlated with air temperature and thus the time of day affects the value obtained.

Turbidity

In the wet season, turbidity (Figure 3.33) was low in the Mountain Stream zone (2 NTU), increased in the middle reaches and decreased in the Lower River. A higher than expected value was recorded at R2 (39), an Upper Foothill site. In comparison, another Upper Foothill site, R5 (Himo River) had much lower turbidity (13). R7 (Muraini) had a high turbidity value, although this may be attributed to rainfall the previous days. Lower Foothill sites had turbidity values ranging from 18 (R3) to 79 (R9). Turbidity in the Mature Lower River was 46 (R11), which is substantially higher than R11A (19) above the confluence with the outflow from the hydropower station. In the dry season, turbidity (Figure 3.5) increased slightly in the Mountain Stream zone (3 to 4 NTU), while the Upper Foothill site was 9 NTU, the Lower Foothill sites varied from 18 to 55 NTU and the Mature Lower River was 39 NTU.

Total Suspended Solids (TSS)

TSS broadly tracked turbidity although in some instances TSS was higher than turbidity, notably site R5, R7 and R8 in the wet season. At R5 there was localized disturbance of the riparian soil, while at R7 recent rain may have elevated TSS levels. The reason for elevated TSS at R8 and R9 is presently unknown, but may be related to organic material suspended in the water column. TSS was higher in Mountain Stream sites and lower at R8 and R9 during the dry season.

Chemical parameters

pH

The pH values showed no or very slight variation among the sites and were mostly close to neutral. They were within the range of 6.61 to 8.42 in the wet season and generally increased slightly to a range of 7.14 to 8.93 in the dry season. The lowest and highest values were consistent at sites amongst the seasons, excluding R7, which was only assessed in the wet season.

Conductivity

Conductivity (Figure 3.34) was lowest in the Mountain Stream and Upper Foothill zones (6.7 to 14.0 mSm^{-1}), except for R2 in the wet season, where it is higher than expected (23.9 mSm^{-1}). The highest conductivity in the wet season was at R8 and R9 (79.6 and 86.8 mSm^{-1} respectively). In the dry season, conductivity values at R3 increased from 49.6 to 140.0 mSm^{-1} and at R12 values increased from 73.2 to 180.7 mSm^{-1}. The remaining sites increased by ≤ 20 mSm^{-1}.

Dissolved Oxygen

Dissolved oxygen concentrations (Figure 3.34) ranged from 5.51 (R3) to 8.94 (R8) in the wet season and 5.03 to 7.75 in the dry season, and were generally lower in the dry season. The exception was site R6 (wet: 0.62 mgl^{-1}; dry: 0.58 mgl^{-1}), which is along the Ruvu River at Kifaru. This river joins Pangani River as a tributary originating from Lake Jipe. There is a substantial amount of decaying material in the river at this site, which may contribute to the extremely low dissolved oxygen concentrations.

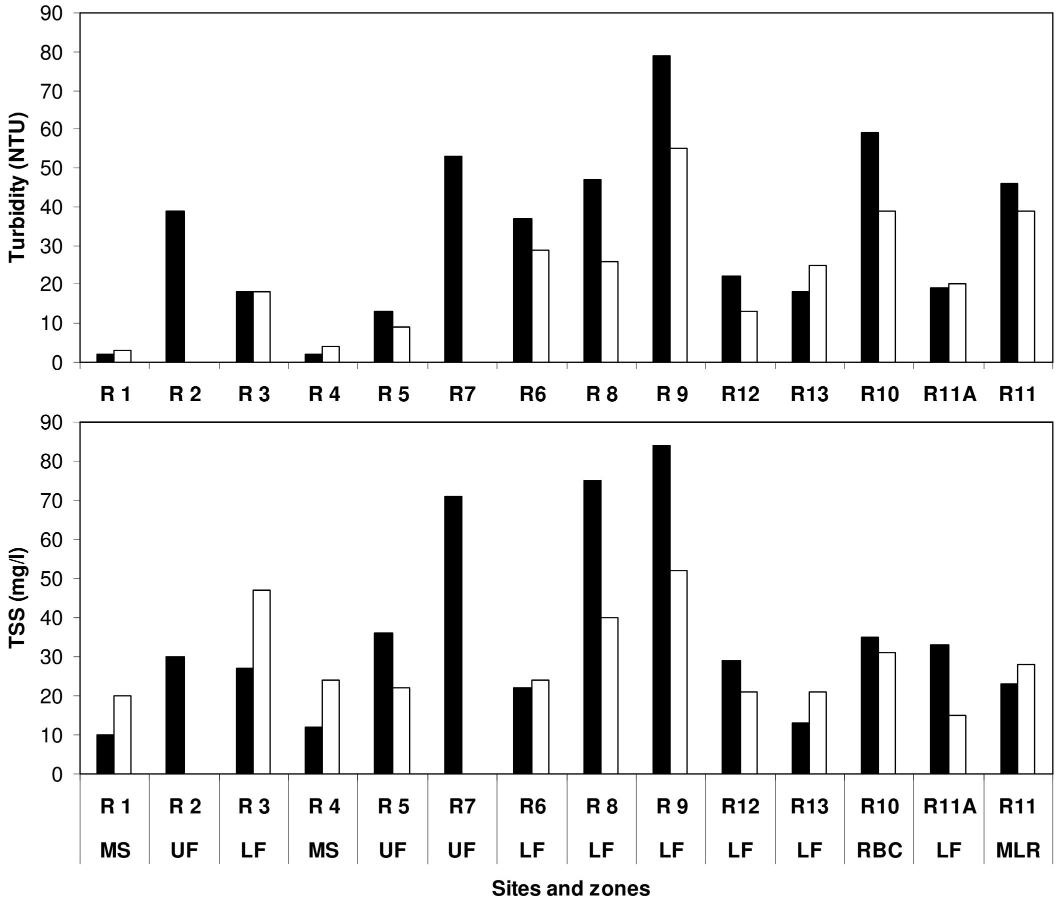


Figure 3.33 Turbidity (NTU) and Total Suspended Solid concentrations (TSS mgl^{-1}) at sites during the wet (solid bar) and dry (open bar) seasons. Zones are indicated.

Nitrogen

Three nitrogen fractions were measured as nitrate-N, nitrite-N and ammonia-N. Total inorganic nitrogen (TN) was calculated by summing nitrate-N, nitrite-N and ammonia-N. TN therefore includes NO3-N, NO2-N and NH3-N. In the wet season, most sites were mesotrophic (0.5 to 2.5 mgl^{-1}: Average Summer Inorganic Nitrogen Concentration, DWAF 1996), except for R7 (2.811 mgl^{-1}), R9 (3.257 $mgl^{-}1$) and R13 (3.863 $mgl^{-}1$) (Figure 3.35), which were eutrophic indicating nutrient enrichment. In the dry season, five sites (R8, R9, R10, R12, R13) had TN in the oligotrophic range (<0.5 mgl^{-1}) and the remainder were mesotrophic.

Phosphorous

Total phosphorus (TP) is expressed as mg l^{-1} phosphate (Table 3.3). In the wet season, TP was between 0.06 and 0.07 mgl^{-1} at R2, R3, R6 and R13, indicating that these sites are eutrophic (DWAF 1996), and < 0.04 mgl^{-1} at all other sites, indicating that these sites were mesotrophic (DWAF 1996). In the dry season R4 and R5 were the only mesotrophic sites, while R1, R3, R6, R8, R11, R12 and R13. R9, R10 and R13 were hypertrophic.

The trophies status was also assessed by comparing the ratio of TP to TN. It is generally the ratio of TP to TN that determines the extent to which a system is enriched and TP is often the limiting nutrient in aquatic ecosystems. On this basis all sites except for R1, R4 and R5 were either eutrophic or hypertrophic.

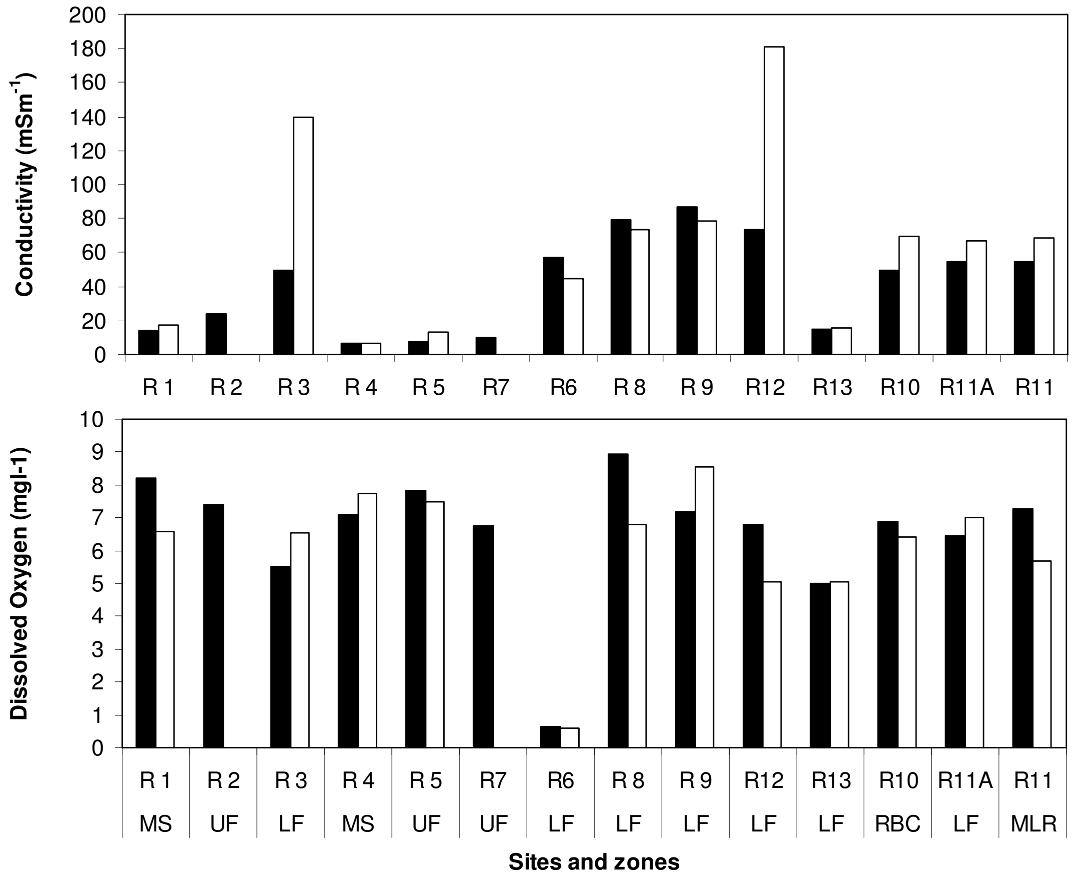


Figure 3.34 Conductivity and dissolved oxygen concentrations at sites during the wet (solid bar) and dry (open bar) seasons. Zones are indicated.

Carbonates and Bicarbonates

In the wet season, carbonates (Table 3.3) were below detection level, except for R8 and R9, where the concentration was 12 mgl^{-1} for each. In the dry season levels were detected at R1, R5, R8, R9, R10, R11A and R11, although it was only at R8 that they were high (132 mgl^{-1}). Bicarbonate varied from 36.6 mgl^{-1} (R7) to 424.6 mgl^{-1} at R8 (Figure 3.36). The concentration increased markedly after NYM dam, presumably because of the geological formation of the area inundated by the dam. Bicarbonate also increased significantly in the dry season at R5, which is also on calcareous soils.

Sulphate

Sulphate (Table 3.3) varied from ≤ 7 mgl^{-1} to 172 mgl^{-1} at R12 in the wet season. In the dry season sulphate was measurable at R3, R10, R11A, R11, R12 and R13, although only R12 had a very high value of 425 mgl^{-1}.

Chloride

Chloride (Table 3.3) values were generally low and varied from 1.9 mgl^{-1} at R5 to 42 mgl^{-1} at R12 in the wet season, and from 2.1 at R3 to 10.9 at R13 in the dry season.

Fluoride

In the wet season, fluoride (Table 3.3) varied from 0.14 mgl^{-1} at R7 to 2.06 mgl^{-1} at R2. In the dry season, it varied from 0.22 at R13 to 2.07 at R1.

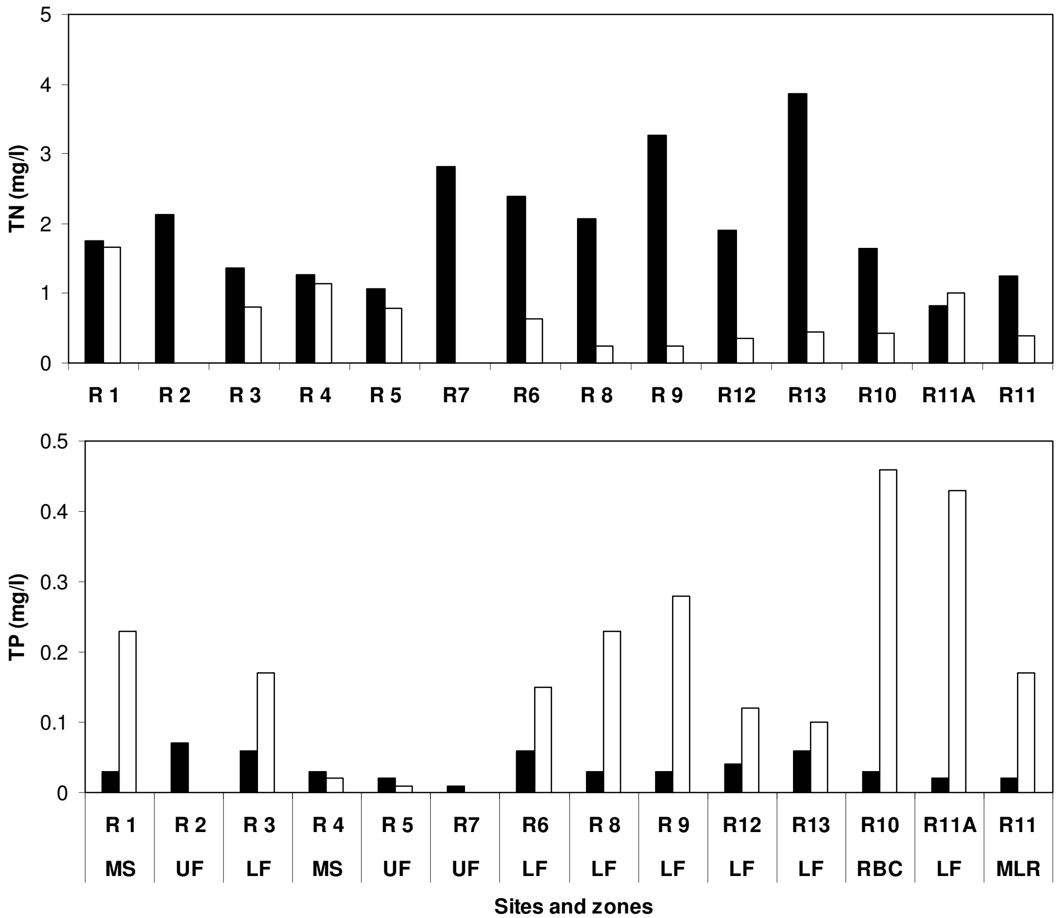


Figure 3.35 Total Nitrogen (TN) and Total Phosphorous (TP) concentrations at sites during the wet (solid bar) and dry (open bar) seasons. Zones are indicated.

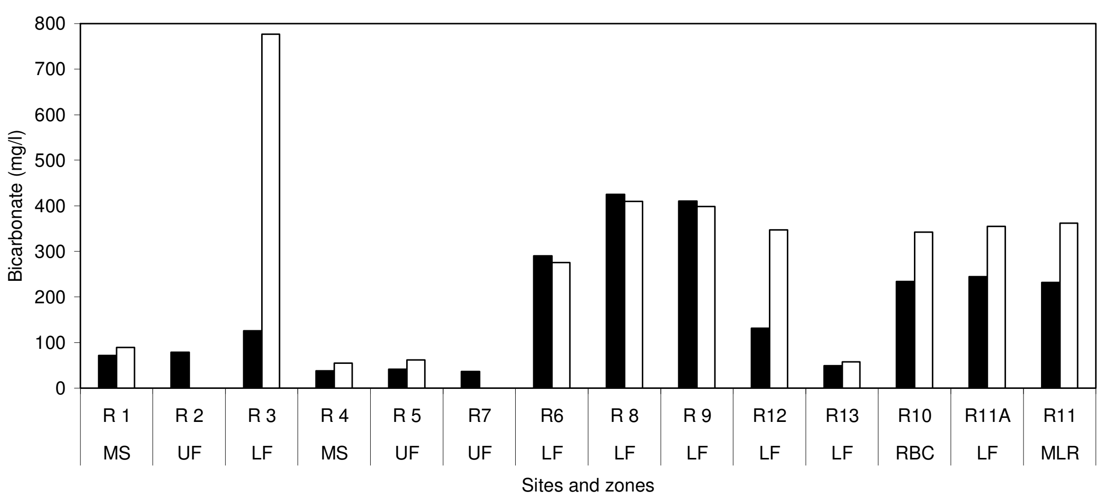


Figure 3.36 Bicarbonate (HCO_3^-) concentrations at sites during the wet (solid bar) and dry (open bar) seasons. Zones are indicated.

Calcium
Calcium (Table 3.3) varied from 2.8 mgl^{-1} at R7 to 16 mgl^{-1} at R6 in the wet season. It varied from 6 mgl^{-1} at R13 to 85 mgl^{-1} at R3 in the dry season.

Magnesium
Magnesium (Table 3.3) varied from 0.73 mgl^{-1} at R1 to 11.9 mgl^{-1} at R8 and R9 in the wet season. It varied from 0.24 mgl^{-1} at R1 to 53 mgl^{-1} at R5 in the dry season.

Iron
Iron (Table 3.3) varied from 0.45 mgl^{-1} at R1 to 3.2 mgl^{-1} at R9 in the wet season. It varied from 0.12 mgl^{-1} at R4 to 2.06 mgl^{-1} at R10 in the dry season.

Manganese
Manganese (Table 3.3) was < 0.06 (the detection limit) at all sites except R11 in the wet season, where it was 0.9 mgl^{-1}. Manganese was not measured in the dry season because of low concentrations in the wet season.

Biological parameters
Chlorophyll *a*
Measured chlorophyll *a* was generally low except for R9 (35.27 μgl^{-1}), R13 (30.81 μgl^{-1}) and R11 (35.27 μgl^{-1}) in the wet season, which indicates modification of the system at these specific sites. These confirm the higher nitrogen levels at R9 and R13 in the wet season. Chlorophyll *a* was not measured in the dry season because of the low concentration measured in the wet season.

Algae
In the wet season, algae were only noted at sites R9 and R10, and in both sites were relatively limited. In the dry season, algae were recorded at five sites, namely R3, R6, R9, R10 and R11A.

Aquatic Macrophytes
Aquatic macrophytes were only present at R10 and R13 during the wet season survey and were noted at R6 in the dry season (*Ceratophyllum demersum* and *Azolla pinnata*) assessed in this survey.

Invertebrates

Biotopes present
The diversity of biotopes (Figure 3.37) at a site determines which biotopes can be sampled and thus influences which invertebrates are recorded. Stones (in and/or out of current) were present at all sites in the mountain stream and upper foothill zones, sites R3, R8, R11A in the lower foothill zone and site R10 in the rejuvenated zone. Stones were absent at R6 (Ruvu R.), R8 and R11 (Pangani R.), R12 (Mkomazi R.) and R13 (Luengela R.). Vegetation (in and/or out of current) was present at all sites except R4 (Ona R.) and R7 (Muraini R.). Aquatic vegetation and gravel were rare, while sand and/or mud were present at most sites.

SASS biotopes
These are the biotopes defined in the SASS sampling protocol. They include stones-in-current (SIC), stones-out-of-current (SOOC), marginal vegetation in current (MVIC), marginal vegetation out of current (MVOC), aquatic vegetation (AQV), gravel (G), sand (S) and mud (M).

Specific biotopes
Specific biotopes divide each SASS biotope further based largely on the hydraulic and substrate conditions. For example, SIC may include the following specific biotopes: riffle, run, boulder rapid, chute, cascade and/or bedrock rapid. Details of these are given for each site in Section 3.1.

Table 3.3 Physical, chemical and biological parameters measured at sites assessed during the river health survey - wet and dry seasons.

River Zone			MS	UF	LF	MS	UF	UF	LF	LF	LF	LF	LF	RBC	LF	MLR	
Site Code			**R 1**	**R 2**	**R 3**	**R 4**	**R 5**	**R7**	**R6**	**R 8**	**R 9**	**R12**	**R13**	**R10**	**R11A**	**R11**	**Butu**
Physical Parameters (Units)	**EDL**	**Season**															
Temperature (^{o}C)		W	18.3	20.1	22.3	18.6	18.3	20.7	20.6	24.1	24.2	25.0	24.5	24.8	25.0	25.4	20.6
		D	21.5	-	25.6	16.7	24.5	-	21.5	23.3	24.5	24.2	24.2	26.4	24.4	25.7	-
Turbidity (NTU)		W	2	39	18	2	13	53	37	47	79	22	18	59	19	46	41
		D	3	-	18	4	9	-	29	26	55	13	25	39	20	39	-
Visual Turbidity (D = Discoloured; O=Opaque)		W	D	O	O	D	D	D	O	O	O	O	O	O	O	D	O
		D	D	-	D	D	D	-	O	O	O	D	O	O	D	O	-
Total Suspended Solids (mg/l)		W	10	30	27	12	36	71	22	75	84	29	13	35	33	23	25
		D	20	-	47	24	22	-	24	40	52	21	21	31	15	28	-
Chemical Parameters																	
pH		W	7.91	7.77	7.53	7.94	8.2	6.61	6.81	8.42	8.42	7.48	6.9	7.92	8.1	7.92	7.12
		D	8.32	-	8.35	7.9	8.32	-	7.14	8.93	8.63	8.16	7.44	8.54	8.46	8.46	-
Conductivity (mSm^{-1})		W	14.01	23.9	49.6	6.7	7.7	10.2	56.8	79.6	86.8	73.2	15.04	49.9	54.5	54.6	89.2
		D	17.52	-	140	6.98	12.9	-	44.9	73.9	78.2	180.7	15.35	69.8	66.8	68.8	-
Dissolved Oxygen (mg/l)		W	8.2	7.38	5.51	7.1	7.84	6.76	0.62	8.94	7.2	6.79	5	6.88	6.45	7.25	7.14
		D	6.56	-	6.54	7.75	7.49	-	0.58	6.78	8.56	5.03	5.05	6.39	7	5.7	-
Nitrates (mg/l NO_3-N)		W	1.7	2	1.3	1.2	1	2.7	1.9	1.9	3.1	1.7	3.8	1.3	0.7	1	1.3
		D	1.6	-	0.6	0.9	0.7	-	0	0	0	0	0	0	0.8	0	-
Nitrites (mg/l NO_2-N)	0.001	W	0.001	0.002	0.01	0.001	0.001	0.001	0.001	0.005	0.007	0.006	0.003	0.005	0.004	0.003	0.001
		D	0.005	-	0.005	0.005	0.002	-	0.001	0.005	0.001	0.003	0.001	0.042	0.004	0.023	-
Ammonia (mg/l NH_3-N)	0.06	W	0.06	0.13	0.05	0.06	0.06	0.11	0.48	0.16	0.15	0.2	0.06	0.33	0.12	0.24	0.42
		D	0.06	-	0.19	0.24	0.09	-	0.53	0.14	0.15	0.25	0.34	0.29	0.21	0.26	-
Total Nitrogen (mg/l)		W	1.761	2.132	1.36	1.261	1.061	2.811	2.381	2.065	3.257	1.906	3.863	1.635	0.824	1.243	
		D	1.665	-	0.795	1.145	0.792	-	0.531	0.145	0.151	0.253	0.341	0.332	1.014	0.283	-
Total Phosphorus (mg/l)	0.01	W	0.03	0.07	0.06	0.03	0.02	0.01	0.06	0.03	0.03	0.04	0.06	0.03	0.02	0.02	0.06
		D	0.23	-	0.17	0.02	0.01	-	0.15	0.23	0.28	0.12	0.1	0.46	0.43	0.17	-
TN: TP		W	58.7	30.46	22.67	42.03	53.05	281.1	39.68	68.83	108.6	47.65	64.38	54.5	41.2	62.15	0
		D	7.239		4.676	57.25	79.2		3.54	0.63	0.539	2.108	3.41	0.722	2.358	1.665	
Carbonate (mg/l)		W	0	0	0	0	0	0	0	12	12	0	0	0	0	0	0

River Zone			MS	UF	LF	MS	UF	UF	LF	LF	LF	LF	LF	RBC	LF	MLR	
Site Code			**R 1**	**R 2**	**R 3**	**R 4**	**R 5**	**R7**	**R6**	**R 8**	**R 9**	**R12**	**R13**	**R10**	**R11A**	**R11**	**Butu**
		D	7.2	-	17	0	4.8	-	0	132	12.6	0	0	5	10.2	7.8	-
Bicarbonates (mg/l)		W	71.9	78.1	126	37.8	41.8	36.6	290	424.6	409.9	131.7	48.8	234	244.6	231.8	24.4
		D	89	-	776	54.5	62		275	409	399	347	57.3	342	355	362	-
Sulphate (mg/l)	7	W	<7	8	20	<7	<7	12	7	12	43	172	16	34	39	60	13
		D	<7	-	62	<7	<7	-	<7	<7	<7	425	7	34	37	34	-
Chloride (mg/l)		W	6	4.1	1.8	1.9	1.9	5.7	4	2.2	2	42	11.3	4	11.4	11	6.7
		D	4.5	-	2.1	5.1	2.2	-	2.6	2.8	3	5.6	10.9	5	2.3	5.7	-
Fluoride (mg/l)	0.02	W	1.62	2.06	0.67	0.37	0.43	0.14	0.64	1.99	1.79	0.59	0.2	0.68	0.68	0.78	0.08
		D	2.07	-	2.01	0.68	0.36	-	0.37	1.49	1.65	0.81	0.22	1.35	1.19	1.22	-
Calcium (mg/l)		W	3.6	4	10	4	4.4	2.8	16	9.6	14	14.8	8	8.4	8.4	14	4
		D	10.8	-	85	10	14.8	-	29.6	25.6	34.4	75.2	6	42.4	40.8	35.2	-
Magnesium (mg/l)		W	0.73	4.1	6.08	1.9	1.95	1.7	10.7	11.9	11.9	11.4	3.4	7.8	9.97	11.7	1.46
		D	0.24	-	53	2.4	5.1	-	23.2	13.2	13.4	37.1	8.8	7.3	7.3	10.3	-
Iron (mg/l)	0.02	W	0.45	0.6	0.5	0.6	1	2.9	0.65	0.75	3.2	1.11	1.75	2.49	1.5	1.76	2.5
		D	0.24	-	0.44	0.12	0.16	-	2.4	0.76	1.76	0.68	1.72	2.06	0.96	2.01	-
Manganese (mg/l)	0.6	W	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	<0.6	0.9	<0.6
		D	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biological Parameters																	
Chlorophyll a (µgl-1)		W	6.16	18.92	16.64	18.92	4.56	14.36	5.70	17.33	35.27	12.77	30.81	18.62	-	29.64	-
		D	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Algae present? (Y=Yes; N=No)		W	N	N	N	N	N	N	N	N	Y	N	N	Y	N	N	-
		D	N	-	Y	N	N	-	Y	N	Y	N	N	Y	Y	N	-
Macrophytes present? (Y=Yes; N=No)		W	N	N	N	N	N	N	N	N	N	N	Y	Y	N	N	-
		D	N	-	N	N	N	-	Y	N	N	N	N	N	N	N	-

* EDL: Estimated Detection Limit; # TN includes NO3-N, NO2-N, NH3-N and Organic Nitrogen; - indicates no sample taken

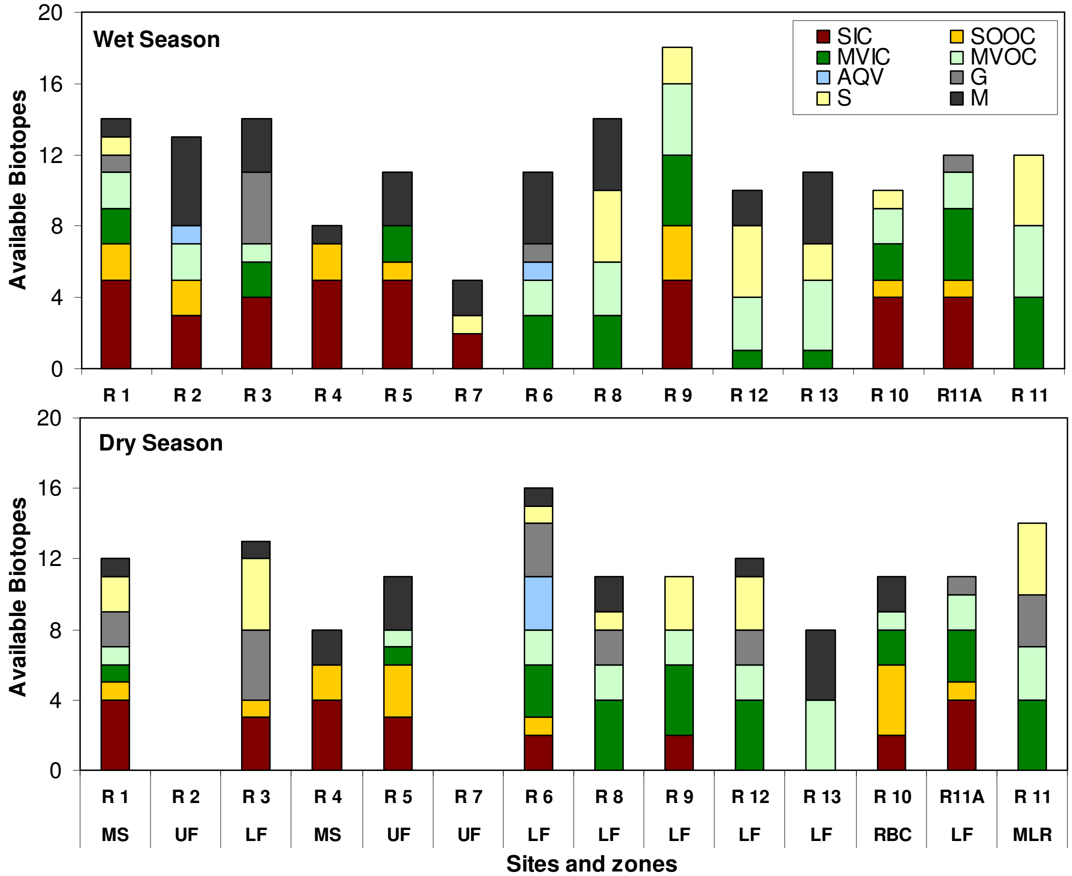


Figure 3.37 Biotopes available at each site for the wet and dry seasons. Biotopes are divided into SIC (stones-in-current), SOOC (stones-out-of-current), MVIC (marginal vegetation-in-current), MVOC (marginal vegetation-out-of-current), AQV (aquatic vegetation), G (Gravel), S (Sand) and M (mud). Values are based on the rating scale. Zones are indicated.

South African Scoring System - SASS5

A total of 54 invertebrate taxa (mostly families) were recorded during the wet and dry season surveys (Appendix C). SASS5 Scores, Number of Taxa and ASPT values are given for the site (i.e. by recording invertebrates in all biotopes and combining to produce a site score, Figure 3.38), and separately for each biotope, i.e. stones (Figure 3.39), vegetation (Figure 3.40) and sand/mud (Figure 3.41). Examination of the combined scores (Figure 3.38) shows a general decrease in SASS5 Scores as one moves from the upper to the lower zones of the rivers. This is not unexpected as lower river zones generally tend to have lower SASS5 Scores, because of the frequent absence of the stone biotope. A more detailed discussion follows on each site, including SASS Scores obtained for the site and for each biotope, in addition to a list of taxa recorded at the site.

Biotopes sampled - Invertebrate Habitat Assessment System (IHAS)

A modified version of the IHAS was used to give an overall indication of the quality and quantity of the biotopes assessed at each site in this survey. Scores were derived for each of the biotopes sampled, namely stones, vegetation and gravel/sand/mud (Figure 3.42). These scores were then summed to give an overall IHAS score for the site. On this basis, IHAS was highest at R1, R5, R9 and R11A; and lowest at R6, R8, R11, R13 and R12 in the wet season. IHAS scores changes slightly in the dry season, notably the presence of stones and gravel at R6 and gravel/sand at R11. IHAS is undertaken so that it is possible to distinguish between a low SASS5 Score and ASPT that is the result of low biotope availability, and a low SASS5 Score and ASPT resulting from a reduction in, for example, water quality.

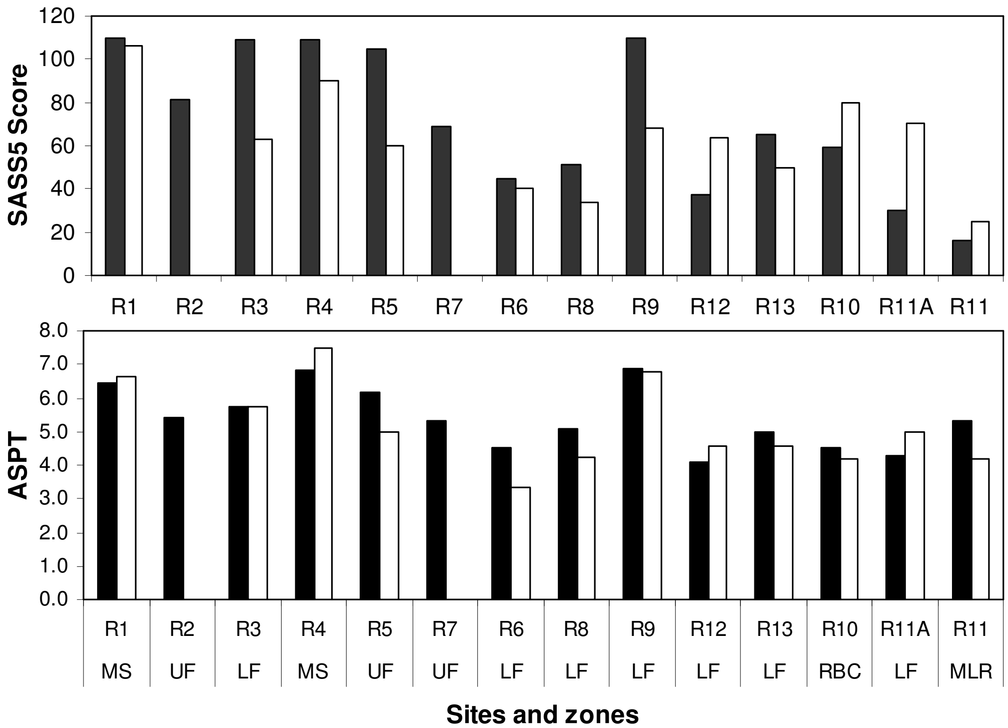


Figure 3.38 SASS5 Scores and ASPT values at sites (i.e. combined scores) assessed at each site during the wet (solid bar) and dry (open bar) seasons. Zones are indicated.

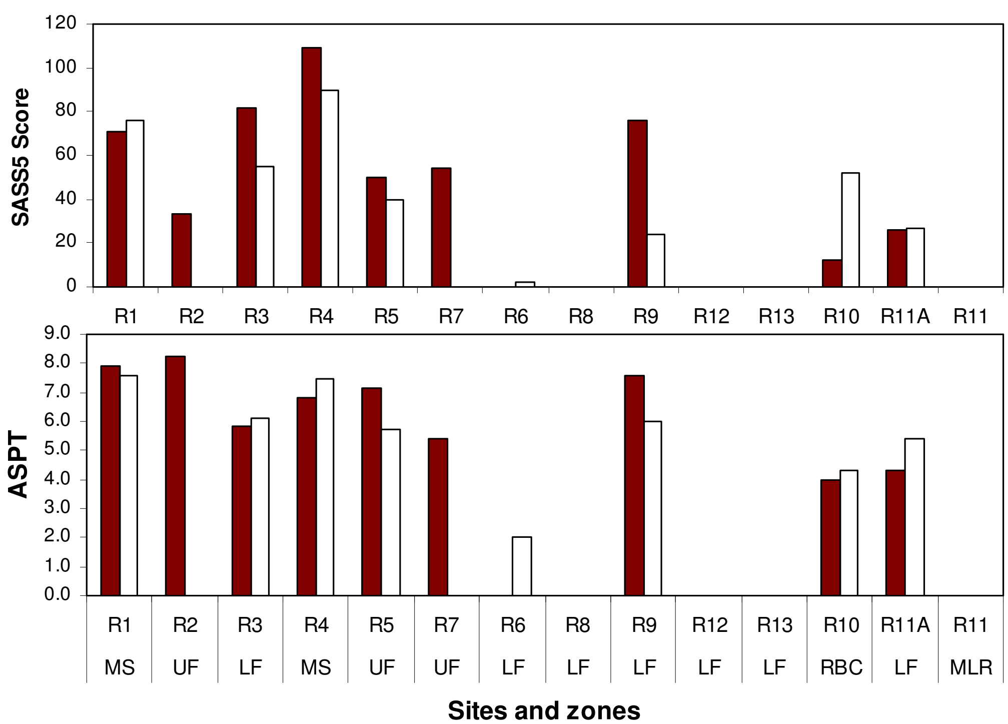


Figure 3.39 SASS5 Scores and ASPT values in the stones biotope at each site during the wet (solid bar) and dry (open bar) seasons. Zones are indicated.

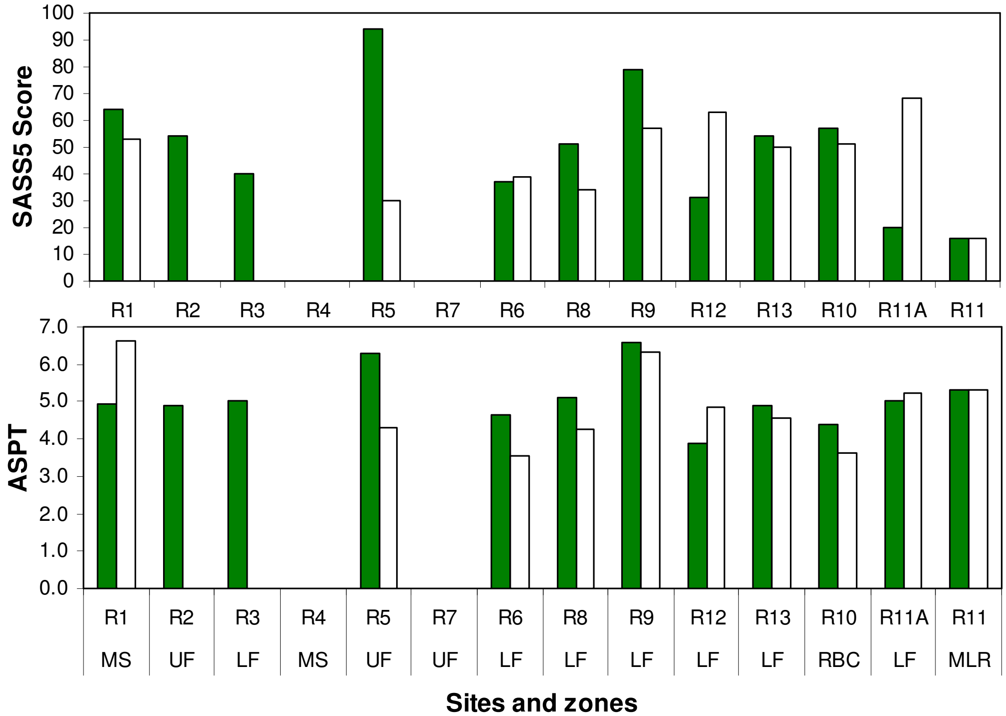


Figure 3.40 SASS5 Scores and ASPT values in the vegetation biotope at each site during the wet (solid bar) and dry (open bar) seasons. Zones are indicated.

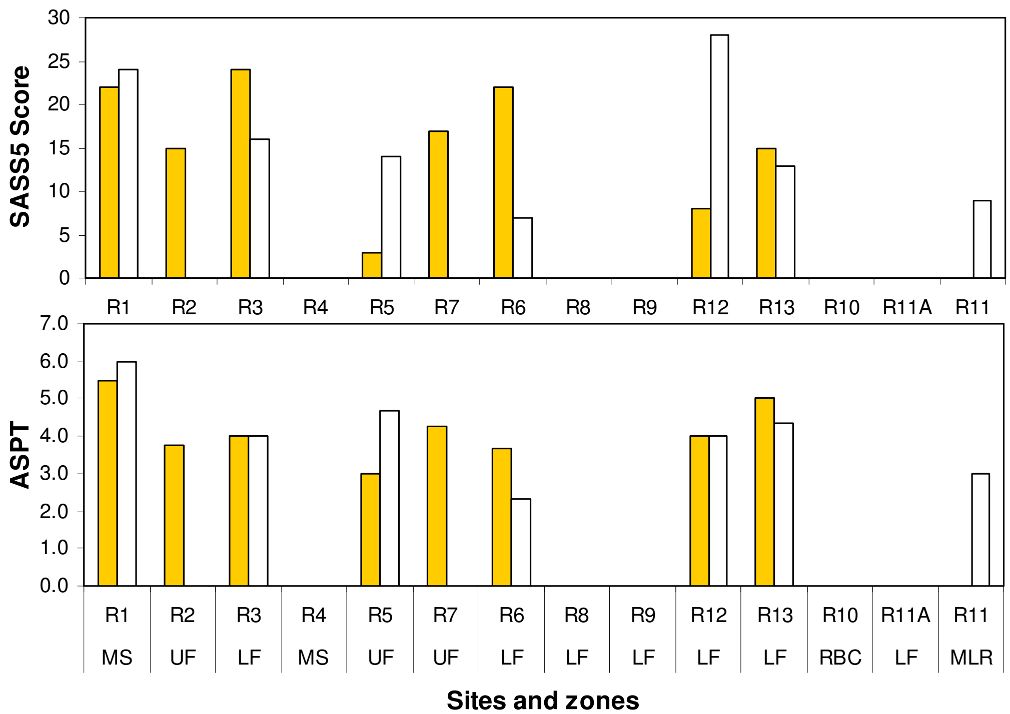


Figure 3.41 SASS5 Scores and ASPT values in the gravel/sand/mud biotope at each site during the wet (solid bar) and dry (open bar) seasons. Zones are indicated.

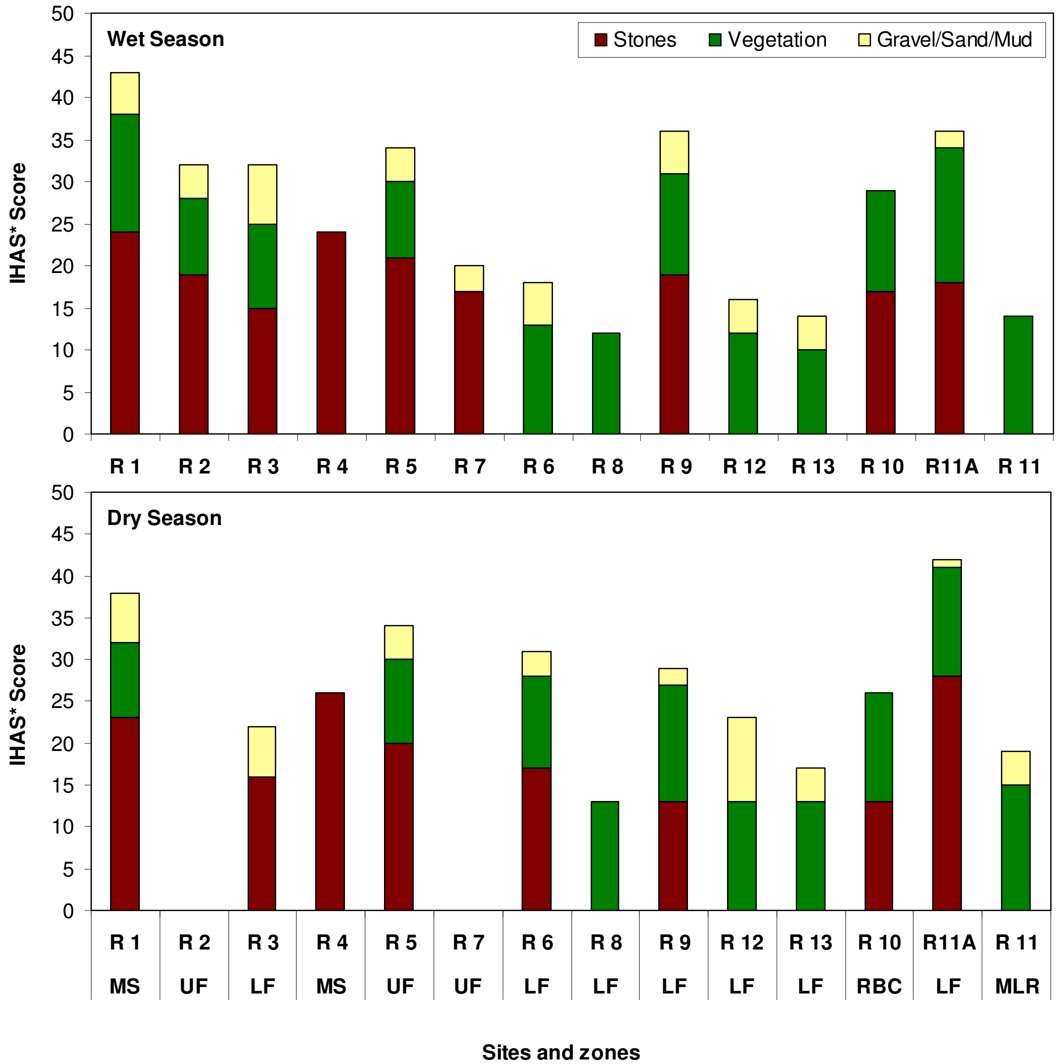


Figure 3.42 IHAS (modified) scores indicting the quality and quantity of biotopes sampled at each site during the wet (solid bar) and dry (open bar) seasons. Zones are indicated.

Fish

Fish habitat

The surveyed area revealed a wide range of habitats (overhanging vegetation, undercut banks, macrophytes, substrate and water column, i.e. depth of water) and velocity-depth classes ranging from shallow-slow flowing (SS), shallow - deep flowing (SD), shallow - fast flowing (FS) to deep fast flowing (FD). During the wet season fish had a lot of cover provided by a relatively deep water column in all zones. Flow conditions varied from site to site. Shallow fast flowing conditions were observed in the mountain streams and the rejuvenation zones, while fast deep flowing conditions dominated the Upper Foothill, Lower Foothill zones and the mature sections of the river. Overhanging riparian vegetation consisting mainly of trees was common in the mountain stream and Upper Foothill zones, while reeds dominated the Lower Foothill areas. Undercut banks were observed in some areas of the Upper foothill zone. Submerged macrophytes were very rare except at site R6 in the Lower Foothill zone where emergent macrophytes were also common. The substrate changed from site to site, with rocks and boulders dominating the Mountain Stream and Rejuvenation zones, gravel common in the Upper Foothill zone and sand/mud common in the Lower Foothill and Mature Lower River zones. The habitat description of each site is given in Table 3.4.

Table 3.4 Velocity-depth classes and cover types available during the wet and dry seasons. The relative abundance was estimated according to the following guideline: 0=absent; 1=rare; 2=sparse; 3=common; 4=abundant, 5=very abundant. Substrate components include rocks (r), boulders (b), cobbles (c), gravel (g), sand (s), fine sediment (m) and woody debris "snags" (w).

Season	Site	Velocity-Depth Classes				Cover Types				
		FD	FS	SD	SS	Over-hanging Veg	Under Cut Banks	Macro-phytes	Substrate	Water Column
Wet	R1	0	5	0	2	1	0	0	4 (b)	3
	R2	4	3	3	1	2	2	0	3 (g)	5
	R3	5	3	1	1	3	3	0	3 (r/s)	5
	R4	5	2	2	2	5	2	0	4 (r)	5
	R5	5	2	1	1	3	3	0	3 (b/c/s)	4
	R6	5	2	1	1	3	2	4	3 (r/w/s)	5
	R7	0	3	3	4	5	4	0	1(g/s)	3
	R8	5	2	2	1	3	0	3	1 (m)	5
	R9	5	1	1	1	4	1	1	2 (r)	5
	R10	3	4	2	2	0	1	2	2 (r)	4
	R11	5	2	1	1	3	0	0	1 (g)	5
	R11A	2	4	1	1	3	0	3	3 (r/g)	3
	R12	2	2	3	3	4	1	3	1 (s)	3
	R13	0	0	2	4	3	1	1	1 (s)	4
Dry	R1	2	5	0	2	1	0	0	4 (b)	3
	R2	0	0	0	0	2	2	0	3 (g)	5
	R3	1	0	3	4	3	3	0	3 (r/s)	5
	R4	1	2	3	3	5	2	0	4 (r)	5
	R5	3	4	3	3	3	3	0	3 (b/c/s)	4
	R6	4	3	4	3	3	2	4	3 (r/w/s)	5
	R7	0	0	0	0	5	4	0	1(g/s)	3
	R8	5	2	2	1	3	0	3	1 (m)	5
	R9	5	1	1	1	4	1	1	2 (r)	5
	R10	1	1	2	4	0	1	0	2 (r)	4
	R11	2	2	1	1	3	0	0	1 (g)	5
	R11A	2	4	1	1	3	0	0	3 (r/g)	3
	R12	0	0	1	5	4	1	3	1 (s)	3
	R13	2	0	3	3	3	1	1	1 (s)	4

Fish diversity

Twenty-three fish species were recorded during this survey. These belonged to 11 families (Table 3.5). This includes identified specimens caught through experimental fishing, observations from local fishers' catches, and information gathered through interviewing local fishers. Description of fish accruing from interviews was only given to the genus or family level. The identified fish families and their representative genera included Cyprinidae (*Barbus*, *Labeo* and *Garra*), Cichlidae (*Tilapia* and *Haplochromis*), Mochokidae (*Synodontis, Chiloglanis*), Mormyridae (*Mormomyrus*), Gobiidae (*Glossogobius*), Characidae (*Brycinus, Rhabdalestes*) Anguiilidae (*Anguilla*), Clariidae (Clarias), Chanidae (Chanos) and Cyprinodontidae (*Northobranchius*). Some of the *Tilapia* specimens could not be identified due to lack of appropriate keys.

Seasonal difference in fish assemblages

It was observed that different types of fish were caught from various sites during the two seasons. Several fish families including Mormyridae, Mochokidae, Anguillidae, Clariidae, Cichlidae, Ambassidae and Chanidae appeared at some sites only during the wet season, while killifish and eels only appeared at two sites during the dry season. Two sites (R2 and R7) could not be sampled because these river sections had dried up. The difference that was observed could possibly be explained by the type of sampling methods used, which determined the types of habitats that could be sampled. If the electro-shocker had been used

Table 3.5 Occurrence of fish species at sites, together with a description of the sampling gear/method used, habitat conditions and general comments

Site (R No)	Sampling gear/method	Family	genus species	Habitat condition and general comments
R1 - Wet	Sweep net	Cyprinidae	*Garra dembeensis*	Very fast flowing rapids, shallow river with lots of boulders. Open in the mid section with dense over hanging trees upstream and downstream
R1 - Dry	Electro-shocker	Cyprinidae	*Garra dembeensis*	
R2 - Wet	Hook and line	Clariidae	*Clarias gariepinus*	Fast flowing - with a pool - riverbed a mixture of pebbles and gravel in upper reaches and mud on the fringes but rocky downstream.
	Interviews	Cichlidae	*Tilapia sparmani* *Tilapia spp.*	
R2 - Dry	-	-	-	River was dry except for a small shallow pool.
R3 - Wet	Gill net	Cyprinidae	*Barbus oxyrhyinchus* *Labeo cylindricus*	Fast flowing river, with a mixture of rocky, pebble, gravel and mud near the banks. Overhanging vegetation common.
	Sweep net	Cyprinidae	*Barbus toppini*	
	Interviews	Cichlidae Clariidae	*Tilapia* spp. *Clarias* spp	
R3 - Dry	Electro-shocker	Cyprinidae Mochokidae	*Labeo cylindricus* *Barbus lineomaculatus* *Garra dembeensis* *Barbus toppini* *Chiloglanis deckenii*	Water level was confined to the deeper middle channel.
R4 - Wet	Sweep net	Cyprinidae	*Garra dembeensis* *Brycinus sadleri*	Very fast flowing river with a rocky bed with lots of boulders and shallow pools, with very abundant overhanging riparian consisting of large trees. Habitat not suitable for setting gillnets, seining or cast netting.
	Interviews	Cichlidae	*Tilapia spp*	
R4 - Dry	Electro-shocker	Cyprinidae	*Garra dembeensis*	
R5 - Wet	Sweep net	Cyprinidae Cyprinodontidae	*Labeo* sp. (Killifish)	Fast flowing river with boulders and cobbles and a pool with some undercut root wards and overhanging trees. Lower reaches open with less overhanging vegetation. Fish caught in backwaters.
	Interviews	Clariidae	Clarias	
R5 - Dry	Electro-shocker	Cyprinidae Cyprinodontidae	*Garra dembeensis* (Killifish)	Water moderately flowing and level slightly reduced.
R6 - Wet	Sweep net	Cyprinidae	Labeo cylindricus	Moderately flowing river. Water very black and anoxic because of rotting aquatic plants (*Ludwigia* and *Typha*) upstream. Riverbed consisted of gravel, sand and mud on the banks. Fish could be see gulping for air at the water surface probably because of very low dissolved oxygen.
	Interviews	Cichlidae Clariidae Cyprinidae Cyprinidae	*Tilapia* spp *Clarias* spp *Labeo* spp *Barbus* spp	
R6 - Dry	Electro-shocker	Cyprinidae Cichlidae Cyprinodontidae	*Barbus toppini* *Tilapia spartmanni* (Killifish)	Water level had decreased, the water colour had become clearer
R7 - Wet	Sweep net	-	-	A seasonal stream with very little water. Riverbed consisted mostly of pebbles and gravel. There was a pool with undercut root wards. Very abundant overhanging vegetation.
	Interviews	Clariidae Cichlidae	*Clarias* spp ?? *Tilapia* spp ??	
R7 - Dry	-	-	-	The stream was completely dry.

Site (R No)	Sampling gear/method	Family	genus species	Habitat condition and general comments
R8 - Wet	Gill net	Cichlidae Cyprinidae Mochokidae	*Tilapia sparmani* *Barbus oxyrhynchus* *Synodontis* spp *Barbus toppini*	The site was moderately open (except for the lower reaches where there were overhanging trees), deep (2m) flowing river with a muddy riverbed. There were lots of hydrophytes mainly *Typha capensis* and *Cyperus alticularis.* There was a very large weir across the river and some funnel bamboo basket traps set at the weir gates. Fishing was carried out around using traps, gill nets, cast nets and hook and line catching big size fish.
	Cast net	Cichlidae Cyprinidae	*Tilapia* spp (4) *Barbus oxyrhychus* *Brycinus* salderi	
	Interviews, observation	Mormyridae Clariidae Anguiilidae Cichlidae Cichlidae Cyprinidae	*Mormyrus* kannume *Clarias* spp *Anguilla* spp *Tilapia* spp *Haplochromis* spp *Labeo* spp	
R8 - Dry	Electro-shocker	Clariidae Cyprinidae Cichlidae	*Clarias gariepinus* *Barbus toppini* *Barbus urotaenia* *Tilapia spp*	The flow conditions had increased slightly because of the controlled discharge from the NYM Hydropower station
	Gill net	-	-	
R9 - Wet	Gill net	Cyprinidae	*Barbus oxyrhynchus*	The site had a wide river ca. 20 m, fast flowing, with a rapid followed by laminar flowing part. The riverbed was rocky then turned into boulders and later into sand with mud at the banks further downstream. Riparian vegetation consisted of largely *Typha* sp. and tall trees. There was a weir with bamboo basket fish traps set across the river at the rapids.
	Interviews	Anguillidae Cyprinidae Cichlidae Palaemonidae Clariidae Cyprinidae Mormyridae	*Anguilla* spp *Barbus* spp *Tilapia* spp *Macrobrachium* spp *Clarias gariepinus* *Labeo* spp *Mormyrus kannum*	
R9 - Dry	Electro-shocker	Cyprinidae Clariidae Cichlidae	*Barbus toppini* *Clarias gariepins* *Tilapia sparmani*	The water level had increased slightly due to release from the NYM dam upstream
R10 - Wet	Small seine net	Cichlidae Clariidae Characidae Cyprinidae Cyprinodontidae	*Tilapia* spp (5) *Clarias gariepinus* *Brycinus sadleri* *Labeo cylindricus* *Killifishes* *Aulonacara* sp	An open river with extensive bedrock and a lot of backwaters
	(interview)	Cyprinidae	*Barbus* sp	
R10 - Dry	Electro-shocker	-	-	Water level slightly reduced due to abstraction upstream to feed the Hale hydropower station.

Site (R No)	Sampling gear/method	Family	genus species	Habitat condition and general comments
R11 - Wet	Hook and line (observation on local fishers catch)	Mochokidae Gobiidae Gobiidae Cichlidae Ambassidae Chanidae	*Synodontis nigromaculatus* *Glossogobius reichii* *G.biocellatus* *Oreochromis spp* *Ambassis urotaenia* *Chanos chanos*	Fast flowing open river of mixed water from the hydropower tail race and hydropower headpond spill over stream. Bottom consisted of a rock that changed into gravel, sand and mud downstream with overhanging trees especially on the left bank and aquatic macrophytes consisting of *Ludwigia jusiodes* and *Polygonum senegalensis*. Many fishermen (> 10) fishing using hand lines.
	Cast net	Ambassidae Channidae	*Ambasis unitaenia* *Chanos chanos*	
	Gill nets	Ambassidae	*Glossogobius reichii*	
	Interviews	Clariidae	*Clarias* sp.???	
R11 - Dry	Electro-shocker	Anguillidae Gobiidae	*Anguilla bicolour bicolour* *Glossogobius reichii* *Glossogobius biocellatus*	Water is released intermittently from the hydropower station tail race due to regular power plant shutoff. Flow in the spill over stream occurred only when the head pond fills up before the plant is switched on again. The gill net caught no fish because the water was released back into the river from the power plant shortly after our arrival at the site.
	Gill net	-	-	
R12 - Wet	Small seine net	Cichlidae Cyprinidae Cyprinidae Clariidae Characidae Mochokidae	*Tilapia sparmani* *Labeo cylindricus* *Barbus jacksonii* *Clarius gariepinus* *Brycinus sadleri* *Synodontis dhonti* ??	Slow flowing river with a sandy bottom and some overhanging vegetation consisting mainly of *Phragmites mauritanus, Sesbania sesban, Cyperus alticulatus*.
R12 - Dry	Electro-shocker	Cichlidae Cyprinidae	*Tilapia sparmani* *Barbus unitaenia*	Water level slightly reduced.
R13 - Wet	Gill nets	Clariidae	*Clarias gariepinus*	Moderate flowing river with a sand/mud bottom. Left side of the middle section open but abundant overhanging vegetation on the right bank, upstream and further downstream
	Interviews	Clariidae Cichlidae Cyprinidae	*Clarias* spp *Tilapia* sp *Labeo* sp	
R13 - Dry	Electro-shocker	Cyprinidae Cyprinidae Characidae Characidae	*Barbus toppini* *Barbus unitaenia* *Brycinus sadleri* *Rhabdalates leleupi*	Water level moderately reduced.

during wet season more species may have been recorded. Change in flow conditions may also have contributed to the observed differences in the type and amount of fish caught. Riverine fish tend to be more abundant during the wet season because tropical riverine species are known to synchronize their spawning activities with the rain season (Welcome 1985).

Conservation status of fish in the Pangani River Basin

Although this survey revealed about 23 fish species it has been reported that about 50 fish species exist in the system. Some of these species (such as *Oreochromis pangani*) are endemic to the Pangani River system. Other species previously described from the Pangani River system by Bernacsek (1980) but not observed during this study include *Oreochromis korogwe*, *O. jipe* (endemic to lake Jipe and considered by IUCN Red list as Critically endangered), *O. esculentus*, O. *ctenochromis pectoralis* , *Synodontis punctulatus, Arius sfricanus, Nothobranchius guentheri, N. palmguistii, Sarotherodon girigan, S. hunter, Astatotilapia bloyeti, and Ctenochromis pectoralis.* Eccles (1992) further lists *Labeo coubie, Barbus pagenscheri, B. paludinosus, B. amphgramma, B. jacksoni, B. kernestenii, B. qudripunctatus,B. radiatus, B. salmo, B. usambarae, B. zanzibaricus, Brycinus affins, Bagrus orientalis, Schilbe moebius, Eutropheus longifilis, Amphilius uranoscopus, Pontanodon podoxys, Aplocheilichthyes kongoranensis, Nothobranchius melanospilus, N. palmquisti, Ambassis gymnocephalus,Anguilla bengalensis labiata, Petersius conserialis, Synodontis afrofischeri, Tilapia rendalli, Oreochromis variabilis, ,Eleotris fusca, Glossogobius giuris,* etc.

Spatial trend of fish in the basin

Of all the fish recorded in the basin Cichlids (*Tilapias*) and minnows/carps (Cyprindae) were the most widely distributed (Table 3.6). They were found in almost all zones except the Mature River Zone. Killifish (Cyprinodontidae) were the next most common and were recorded in all zones except the mountain streams and the lower mature zone. The least common families were Gobies (Gobiidae), Chanidae and Ambassidae, which were confined to the Mature River Zone. Eels (Anguillidae), African tetras (Characidae) and the catfishes: Squakers (Mochokidae) and catfish (Clariidae) had limited distribution.

Table 3.6 Distribution of fish in the Pangani River basin (W = wet-season, D = dry-season)

Family	River zones				
	Mountain stream	Upper Foothill	Lower Foothill	Rejuvenated Bedrock Cascade	Mature Lower River
Cyprinidae	WD	WD	WD	W	
Cichlidae	W	WD	WD	W	
Mochokidae			WD		W
Mormyridae			W		
Gobiidae					WD
Characidae			WD	W	
Anguiilidae			W		D
Clariidae		W	WD		
Cyprinodontidae		WD	D	W	
Ambassidae					W
Chanidae					W

The Lower Foothill recorded the highest diversity of fishes of all the zones, followed by the Mature River Zone. The least diverse was the Mountain Stream zone in which only the minnow *Garra dembeensis* was caught, although there were some reports from local people that in the past cichlids were also found. The distribution of the different groups of fish in various zones is mainly determined by the adaptations of the fishes to live in particular habitats. For example, *Garra dembeensis* has a modified holdfast organ that enables it to cling to rocks in the mountain streams. Other fishes such as *Labeo* sp. and *Chiloglanis* sp.

have similar adaptations and are found in various sections of the river where suitable habitats such as rocky substrate occur. Some fish e.g. Gobies (Glossogobius spp.), Milkfish (*Chanos chanos*), and Ambassids (Ambassis unitaenia) that are found in the Lower Mature River are euryhaline, migrating between the ocean and the river. Because of the landscape barrier formed by the Pangani Falls Hydropower station these fish cannot migrate further upstream. The characteristics of various fish species are discussed in Table 3.7 together with the potential threats to them.

Riparian Vegetation

A total of 233 plant species have been identified to the genus level including trees, shrubs, herbs, grasses, sedges and reeds. The width of the riparian vegetation varied from 5 to 200 m (left and right bank) (Table 3.8). The distribution of vegetation types and their cover estimates from each site is given in
Table 3.9 and Table 3.10 (for sites with a floodplain), and the occurrence of invasive vegetation is listed in Table 3.11. Table 3.12 provides an estimate of canopy cover of the vegetation from each site, indicating the vegetation stratification. Appendix D lists all plant species recorded and identified in the study as well as their status and occurrence in the sites. Appendix E is a tentative checklist of all species recorded in the Pangani River Basin during this survey.

Table 3.7 The width of the riparian vegetation at each site

Width (m)	Site Code												
	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13
Left Bank	30	40	50, 50	70	10	10	150	10	10	5	70	45	2, 120
Right Bank	5	10	40, 90	80	70	18	200	15	5	5	5	105	5, 100

Note: For R3 and R13 the width includes the Riparian one (first measure) and the Floodplain (second measure).

Table 3.8 Distribution of vegetation types and cover estimates at each site (0=absence; 1= rare; 2= sparse; 3= common; 4= abundant; 5 = entire)

Veg. Type	Left Dry Bank											Right Dry Bank										
	Site Code											Site Code										
	R1	R2	R4	R5	R6	R7	R8	R9	R10	R11	R12	R1	R2	R4	R5	R6	R7	R8	R9	R10	R11	R12
Trees	2	3	3	2	2	5	3	2	1	4	1	1	2	3	4	2	5	4	1	1	2	1
Shrubs	4	4	4	3	2	5	3	2	2	4	0	3	2	4	5	3	5	3	2	3	2	0
Reeds	0	0	0	0	1	0	4	1	0	0	3	0	0	0	0	1	0	4	1	0	0	3
Sedges	1	0	0	0	2	0	3	3	2	1	4	0	0	0	1	2	0	2	3	2	1	4
Grass	2	2	1	0	2	1	3	4	3	3	2	1	0	1	1	3	0	2	4	3	4	2
Bare ground	0	1	0	2	2	3	2	0	2	0	1	0	3	0	0	1	3	1	0	1	1	1

Table 3.9 Distribution of vegetation types and cover estimates at sites R3 and R13 (0=absence; 1= rare; 2= sparse; 3= common; 4= abundant; 5 = entire)

	Left Bank				Right bank			
Vegetation type	Riparian Zone		Floodplain		Riparian Zone		Floodplain	
	R3	R13	R3	R13	R3	R13	R3	R13
Trees	4	2	2	1	4	3	2	2
Shrubs	2	2	4	1	2	3	3	2
Reeds	0	2	0	0	0	2	0	0
Sedges	1	1	0	1	0	2	0	1
Grass	2	5	3	5	1	2	3	4
Bare ground	2	0	2	0	1	0	1	0

Table 3.10 Characteristics and threats to fish known for the Pangani River basin

Species	Economic importance	Distribution	Habits and habitat	Peculiar Habits	Resilience to reduced populations	Red list status
Glossogobius biocellatus	Fisheries	Wide		Amphidromous	high	Near threatened
Clarias gariepinus	Fisheries, Aquaculture game	Wide	Prefer quite waters, but may inhabit fast flowing habitats	Potamodromous, tolerant to extreme environmental conditions	medium	none
Brycinus sadleri	Fisheries	Pan African	Pools near *Papyrus* vegetation	-	high	none
Tilapia sparmani	Fisheries Aquaculture, Game	Pan African	Favours areas where plant cover exists	Potamodromous	high	none
Synodontis nigromaculatus	Fisheries, Aquaculture, Aquarium	Pan African	Marginal vegetation of flowing riverine channel	-	high	none
Mormyrus kannume	Fisheries, Game, Aquarium	East Africa		-	medium	none
Anguilla bicolour bicolor	Fisheries	Indo-Pacific	Marshy habitats, rocky bottoms and deeper pools	Catadromous	low	none
Garra dembeensis	Fisheries	Pan African	Rapids and wave washed rocks	-	high	none
Barbus toppini	Fisheries, Aquarium	Pan African	Shallow vegetated streams	Potamodromous	low	none
Labeo cylindricus	Fisheries , Aquarium	Southern Africa	Favours clear running water in rocky habitats	Potamodromous	Low	none
Barbus oxyrhynchus	Fisheries	Africa		Potamodromous	low	Least concern
Barbus urotaenina	Fisheries	Africa		Potamodromous	high	none
Ambasis unitaenia	Fisheries	Indo-Pacific		Amphidromous	high	none
Chiloglanis deckenii	Fisheries	Tanzanian east coast rivers		-	high	

Table 3.11 Occurrence of invasive vegetation at sites in the study area (0=absence; 1= rare; 2= sparse; 3= common; 4= abundant; 5 = entire)

	Left Bank													Right Bank												
Invasive vegetation	**Site Code**													**Site Code**												
Zone	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	**R10**	**R11**	**R12**	**R13**	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	**R10**	**R11**	**R12**	**R13**
Exotic species	3	0	0	2	1	1	2	0	0	2	1	5	0	4	1	0	2	1	1	2	0	0	2	1	5	0
Reeds	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Terrestrial Plants	2	2	0	0	0	0	0	0	0	0	0	1	0	2	2	0	0	0	0	0	0	0	0	0	1	0

Table 3.12 Estimated canopy cover (%) of the vegetation from each site, indicating the vegetation stratification

Left Bank														Right Bank												
Canopy cover %	**Site Code**													**Site Code**												
Zone	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	**R10**	**R11**	**R12**	**R13**	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	**R10**	**R11**	**R12**	**R13**
Trees layer	40	50	60	60	20	10	100	35	5	2	65	0	40	45	30	65	40	60	2	100	40	30	2	2	0	2
Shrub layer	85	75	20	30	30	20	30	10	2	5	90	10	40	50	40	50	40	85	40	60	15	40	5	5	20	10
Herb layer	90	95	70	80	50	30	30	3	100	90	100	50	100	10	30	80	75	30	100	40	40	80	90	80	50	100

Information contributing to the environmental flow assessment

Whilst this study has focused on an assessment of river health, much of the data gathered can be of use in an environmental flow assessment. To this end, focused questions aimed at providing additional information on environmental flows, have been addressed. Data are summarised in Appendix F.

3.3 General conclusions

River health varied from site to site, in response to both natural changes within the catchment and anthropogenic impacts that have modified the water quantity and/or quality of the river system. This survey has provides a solid platform apon which future assessments in the Pangani River Basin may be based.

In addition to the results presented in this report, team members responsible for the river health survey have learnt a great deal during this exercise. They should be well equipped to undertake similar surveys within Tanzania, thereby enhancing the understanding of river systems in the country and allowing for management based on river health knowledge that includes abiotic and biotic components.

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APPENDIX A: Criteria to consider when selecting sites for a river health assessment

The site should:

- be representative of the streams or rivers in the zone - this implies that homogeneous regions within the geographic area under consideration need to be identified.
- If a *reference* site, i.e. representing the natural or least-impacted condition, the site should be minimally-disturbed,
- If a *monitoring* site, the site should capture the anthropogenic impacts in the particular river reach or zone. *Note: if localised impacts at a site such as a bridge modify the site to the extent that the more general impact in the reach is not likely to be assessed, then an alternative site should be sought.*
- have an appropriate variety of biotopes and substrates.
- be relatively accessible and safe during sampling operations.
- if a *reference* site, if possible, have a natural channel and stable banks.
- if a *reference* site, possible, have a natural hydrograph.
- if a *reference* site, possible, have natural riparian vegetation.

The site could also:

- have links to existing on-going monitoring projects, e.g. water quality monitoring
- be situated nearby flow gauging stations (in order to link with existing hydrological and water chemistry data).

APPENDIX B: Details of the analysis methods for water chemistry

PARAMETER	METHOD	SUMMARY OF THE METHOD
pH	Electrometric-with pH model-WTW pH 95	Analysed *in situ* by dipping the electrode in fast flows of the river.
Electrical conductivity	Electrometric -with HACH model -sension5	Analysed *in situ* by dipping the electrode in fast flows of the river.
Temperature	Electrometric -with HACH model -sension5	Analysed *in situ* by dipping the electrode in fast flows of the river.
Dissolved oxygen	Electrometric -with JENWAY - 970 DO_2 Meter	Analysed *in situ* by dipping the electrode in fast flows of the river.
Total Suspended solids	Photometric method Using DREL/2000 Spectrophotometer	Water sample is directly measured after blending in a blender.
Turbidity	Attenuated Radiation Method, using DREL/2000 Specrophotometer	Formazin standards are used to for calibration and readings are taken using Formazin attenuation Units (FAU). A 4000NTU Formazin stock standard is also defined as 4000 FAU.
Nitrate (NO_3^- -N)	Colorimetric using DREL/2000 Method -Cadmium reduction	Cadmium metal reduces nitrates present in the sample to nitrite. The nitrite ion reacts in an acidic medium with sulphanilic acid to form an intermediate diazonium salt, which couples to gentisic acid to form an amber-coloured product.
Nitrogen, Ammonia (NH_3-N)	Colorimetric using DREL/2000. Method - Nessler	Mineral Stabilizer complexes hardness in the sample. The Polyvinyl Alcohol Dispensing Agent aids the colour formation in the reaction of Nessler reagent with ammonium ions. A yellow colour is formed proportional to the ammonia concentration.
Total Phosphorous	Colorimetric using DREL/2000 Method - Acid Persulphate Digestion	Phosphate present in organic and condensed inorganic forms (meta-pyro-or other polyphosphates) are converted to reactive orthophosphate before analysis. Pretreatment of the sample with acid and heat provides the condition for hydrolysis of the condensed inorganic forms. Organic phosphates are converted to orthophosphate by heating with acid and persulphate.
Sulphate	Colorimetric using DREL/2000 Spectrophotometer -SulfaVer 4 Method	Sulphate ions in the sample react with barium in SulfaVer 4 Reagent and form barium sulphate turbidity. The amount of turbidity formed is proportional to the sulphate concentration.
Fluoride	Colorimetric with DREL/2000 - Method SPADNS	Fluoride reacts with a red zirconium-dye solution to form a colourless complex, thus bleaching the red colour in an amount proportional to the uoride concentration.
Iron, total	Colorimetric using DREL/2000 Method - FerroVer	FerroVer Reagent reacts with all soluble iron and most insoluble forms of iron in the sample, to produce soluble ferrous iron. This reacts with the 1,10-phenanthroline indicator to form an orange colour in proportional to the iron concentration.

PARAMETER	METHOD	SUMMARY OF THE METHOD
Manganese	Colorimetric using DREL/2000 Method - Periodate Oxidation	Manganese in the sample is oxidized to the purple permanganate state by sodium periodate, after buffering the sample with citrate. The purple colour is directly proportional to the manganese concentration.
Calcium	Titrimetric method	Calcium is titrated with EDTA 0.0800N after remoning magnesium interference by pH adjustment. After all calcium is complexed by EDTA, CalVer 2 indicator changes colour from red to blue, signaling the end point.
Magnesium	Titration/calculation	Hardness titration with EDTA (0.0800N) then magnesium is calculated from the differences in the Hardness and Calcium titre values.
Carbonate and Bicarbonate	Titration Method	Standard titration with 0.02N hydrochloric acid and phenolphthalein indicator followed by methyl orange indicator
Chloride	Titration Method	Mercuric Nitrate (0.2256/2.256N) titrant, and diphenylcarbazone indicator

Chlorophyll 'a' determination

Method adapted from APHA (1995) and Talling and Driver (1961).

Materials

- Membrane filters (0.45 µm pore size)
- 90% acetone
- Centrifuge test tubes
- Filtration pump and unit
- Measuring cylinder

Method

- Known volume of water sample is filtered through membrane filters by gentle vacuum filtration.
- Measure 10 ml of 90% acetone into a centrifuge tube (or other glass vial chosen) and immerse the filter with its residue for extraction of chlorophyll 'a'.
- Then cover the vial, shake to ensure complete dissolve of the membrane. Cover the vial with foil paper to avoid light (or samples stored in dark glass bottles). Keep cool at 4^{o}C.
- However for our samples, we froze the filters until were brought to the laboratory where:
- Leave the sample overnight, and then the sample is homogenized by centrifuge at 3000rpm for ten minutes.
- Measure chlorophyll 'a' in the spectrophotometer at 750 nm and 663 nm using a glass cuvette

Chlorophyll 'a' concentration is then determined using the formulae:

Chl. 'a', µg/L = (11.40(E663-E750)* V1)/(V2*L) (Talling & driver 1961)

Where: 11.4= absorption coefficient of chlorophyll a; V1 = volume extract in ml; V2= volume of the filtered water sample in L; L = light path length of the cuvette; E663, E750 = optical densities for the samples

APPENDIX C: Invertebrate taxa recorded during the wet (W) and dry (D) season surveys

Group	Taxon	R1	R2	R3	R4	R5	R7	R6	R8	R9	R12	R13	R10	R11A	R11
Platyhelminthes	Turbellaria				W										
Annelida	Oligochaeta		W	W			W	D			D		D		D
	Hirudinea											D	WD		
Crustacea	Potamonautidae	D		D	WD	WD	W					W	WD		
	Atyidae													WD	WD
	Palaemonidae													D	
Arachnida	Hydracarina			D	WD	W				W					
Ephemeroptera	Baetidae 1 Sp						W	WD						W	
	Baetidae 2 Sp			D		D			W		WD	W	WD	D	
	Baetidae >2 Sp	WD	W	W	WD	W				WD					
	Caenidae	WD	W	D		D			W		D		D	D	
	Heptageniidae	WD	W		WD	WD									
	Leptophlebiidae			WD	WD										
	Tricorythidae	WD		D	WD	W				WD					
Odonata	Calopterygidae								W	WD	D		W		
	Chlorocyphidae			W											
	Coenagrionidae	W	W	W		WD		D	D	WD	WD	W	WD	W	
	Aeshnidae	WD				W						W			
	Corduliidae			W					D			W			
	Gomphidae	D		W	W	WD				W	WD		D		
	Libellulidae	W		WD	W					WD	D	W	WD	WD	
Lepidoptera	Crambidae						W			W					
Hemiptera	Belastomatidae		W	W		W		WD	WD		WD	WD	W		W
	Corixidae	W	W	WD				WD	D	W		D	D		D
	Gerridae		W					WD	W						
	Hydrometridae		W	W				W				D		D	
	Naucoridae	WD	W	W		W		W		WD		D	WD	D	
	Nepidae							D	D						
	Notonectidae		W						D			W	D	D	D
	Pleidae							D							

Group	Taxon	R1	R2	R3	R4	R5	R7	R6	R8	R9	R12	R13	R10	R11A	R11
	Veliidae/Mesoveliidae	D	W	W	WD	D		W	WD	WD	W	WD	WD	D	WD
Trichoptera	Ecnomidae			W											
	Hydropsychidae 1 Sp	D				D			W		D		WD	D	
	Hydropsychidae 2 Sp	W	W	WD	WD	W	W			D					
	Hydropsychidae > 2 Sp									W					
	Leptoceridae	WD			W	W				WD		W			
Coleoptera	Dytiscidae	W	W	W		W	W	WD	WD	W	D	WD		D	D
	Elmidae/Dryopidae			D	WD		W								
	Gyrinidae	WD		WD				W			D	WD	D		
	Hydrophilidae						W					D			
	Psephenidae	W			WD										
Diptera	Athericidae	D					W								
	Ceratopogonidae	W				WD	W								
	Chironomidae	WD	W	WD	WD	WD	W	WD	W	W	WD		WD	WD	
	Culicidae													D	
	Ephydridae						W								
	Simuliidae	WD		W	WD	W			W	WD	D		D		
	Syrphidae														
	Tabanidae						W						D		
	Tipulidae	D													
Gastropoda	Ampullaridae										W				
	Ancylidae					D									
	Lymnaeidae							D					D		
	Planorbidae					D		D							
	Thiaridae					W					WD	D	W	WD	
	Viviparidae										W	WD	WD	W	

APPENDIX D: Occurrence of individual plant species at sites assessed during the river health survey

Key for the plant Habit: T = Tree, S = Shrub, H = Herb, CL = Climber, G = Grass, SG = Sedge, L = Liana, FN = Fern, RD = Reeds

Species name	Habit	Status	Site												
			R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13
Abutilon mauritianum	H	Terrestrial		+				+		+				+	+
Acacia albida	T	Terrestrial								+					
Acacia brevispica	L	Terrestrial					+								
Acacia polyacantha	T	Catchment species											+		
Acacia robusta	T	Terrestrial							+	+	+				
Acacia xanthophloea	T	Water loving plant		+	+			+		+	+				
Acalypha ornata	H	Terrestrial	+				+								+
Acalypha fruticosa	H	Terrestrial													+
Achyranthes aspera	H	Terrestrial		+	+			+	+	+					
Acrostichum aureum	FN	Water loving plant									+				
Adenia rumicifolia	L	Catchment species	+						+						
Agave sisalana	H	Crop				+									
Ageratum conyzoides	H	Terrestrial	+			+									
Albizia glaberrima	T	Catchment species		+			+		+	+					+
Albizia gummifera	T	Terrestrial				+			+		+				
Albizia petersiana	T	Terrestrial					+								
Albizia schimperiana	T	Catchment species	+			+									
Allpohylus africanus	S	Terrestrial				+									
Aloe lateritia	H	Terrestrial				+									
Amaranthus hybridus	H	Terrestrial									+			+	
Aneilema aequinoctiale	H	Terrestrial	+												
Annona senegalensis	T	Terrestrial				+									
Antidesma venosum	S	Terrestrial													+
Argemone mexicana	H	Invasive species	+	+											
Artocarpus integra	T	Crop										+			
Astripomoea malvacea	CL	Terrestrial									+				
Asystasia gangetica	H	Terrestrial	+					+							
Azidarachta indica	T	Invasive species						+					+		
Bambusa vulgaris	S	Invasive species							+						
Barringtonia racemosa	T	Water loving plant								+			+		+
Bauhinia tomentosa	S	Terrestrial	+			+									
Bidens pilosa	H	Terrestrial	+												
Blumea aurita	H	Terrestrial	+												
Boerhavia repens	H	Terrestrial		+			+			+					
Bombax rhodognaphalon	T	Terrestrial											+		
Boscia angustifolia	T	Terrestrial					+								
Brachiaria serrata	G	Terrestrial		+											
Bridelia cathartica	T	Terrestrial											+		
Bridelia micrantha	T	Terrestrial	+				+								
Caesalpinia bonduc	L	Terrestrial				+									
Caesalpinia decapitala	L	Invasive species	+			+	+								
Calanchoe prittwitzii	H	Terrestrial				+									
Canna indica	H	Invasive species	+												
Cassia didymobotrya	S	Invasive species	+												
Cassia floribunda	S	Invasive species	+	+			+	+	+	+					
Cassia mimosoides	H	Terrestrial						+					+		+
Cassia siamea	T	Invasive species											+		

Species name	Habit	Status	Site												
Celtis africana	T	Catchment species							+						
Cenesio stuhlmannii	CL	Terrestrial				+									
Cenna spectabilis	S	Terrestrial		+											
Ceropergia distincta	CL	Terrestrial			+										
Chaetachme aristata	S	Terrestrial					+	+							
Chloris gayana	G	Terrestrial	+					+							
Cissampelos pereira	CL	Terrestrial			+			+			+		+		+
Cissus cordifolia	CL	Terrestrial							+						
Cissus intergrifolia	CL	Terrestrial					+								
Cissus quandrangularis	CL	Terrestrial					+								
Cissus rotundifolia	CL	Terrestrial					+								
Cirtus limonia						+									
Clausena anisata	S	Terrestrial					+								
Clerodendrum rotundifolia	S	Terrestrial	+												
Cocos nucifera	T	Terrestrial										+		+	
Combretum pentagonum	S	Terrestrial													+
Commelina beghalensis	H	Terrestrial	+	+		+					+		+		+
Commiphora pteleifolia	T	Terrestrial					+								
Corchorus aestuans	H	Terrestrial											+		
Cordia abyssinica	T	Terrestrial	+			+									
Cordia sinensis	T	Terrestrial			+					+					
Costus afer	H	Water loving plant	+												
Crotalaria laburnifolia	H	Terrestrial											+		
Croton macrostachyus	T	Catchment species	+												
Culocasia esculenta	H	Crop								+					
Cupsicum frutescens	H	Crop							+						
Cussonia arborea	T	Terrestrial					+								
Cynodon dactylon	G	Terrestrial						+			+				
Cynodon nlemfuens	G	Terrestrial		+	+					+	+	+			+
Cyperus alticulatus	SG	Aquatic plant						+		+		+		+	
Cyperus distans	SG	Aquatic plant					+	+		+			+		
Cyperus exaltatus	SG	Aquatic plant						+		+	+				+
Cyperus papyrus	SG	Aquatic plant						+							
Cyperus rotundus	SG	Aquatic plant										+		+	+
Cyperus rotundus	SG	Aquatic plant	+					+							
Dacyloctenium geminatum	G	Terrestrial		+	+			+				+			
Dalbergia obovata	L					+									
Datura arborea	H					+									
Desmodium repandum	H		+												
Dichanthium caricosum	G												+		+
Digitaria milanjiana	G		+								+	+			+
Drymaria cordata	H	Aquatic plant	+												
Drypetes gerrardii	T						+								
Drypetes natalensis	T						+								
Echnochloa scabra	G										+	+			
Ehretia amoena	T										+				
Elaeis guineensis	T							+	+	+		+			+
Englerophytum natalense	S					+			+						
Entada abyssinica	T								+						
Eragrostis aspera	G				+										
Erythroccocca bongensis	S			+											
Euclea natalensis	S								+		+				
Euphorbia nyikae	T	Drought loving plant					+								
Euphorbia tirucalli	T	Drought loving plant					+								

Species name	Habit	Status	Site												
Ficus capreifolia	T	Catchment species		+									+		+
Ficus exasperata	T	Catchment species	+						+				+		+
Ficus sansibarica ssp.sansibarica	T	Catchment species					+								
Ficus mucuso	S	Catchment species	+												
Ficus sur	T	Catchment species		+	+		+	+		+		+	+	+	+
Ficus thonningii	T	Catchment species				+	+	+							
Ficus vallis-choudae	T	Catchment species	+			+	+								
Ficus ingens	T	Catchment species					+								
Fimbristylis ferruginea	SG	Aquatic plant									+				
Flabellaria paniculata	CL	Terrestrial	+												
Flacourtia indica	T	Terrestrial				+									
Flagellaria guineensis	CL	Terrestrial													+
Flueggea virosa	S	Terrestrial									+				+
Galinsona parviflora	H	Terrestrial	+												
Garcinia livingstonei	T	Terrestrial						+							
Gardenia transvenulosa	S	Terrestrial									+				
Glycine wightii	CL	Terrestrial		+			+								
Grevilea robusta	T	Terrestrial	+												
Grewia conocarpa	S	Terrestrial							+						
Grewia mollis	S	Terrestrial					+								
Haplocoelium foliolosum	T	Terrestrial							+						
Harrisonia abyssinica	S	Terrestrial								+					
Heliotropium indicum	H	Terrestrial									+				
Hibiscus cannabinus	H	Water loving plant						+							
Hibiscus esculenta	H	Crop									+			+	
Hibiscus micranthus	H	Terrestrial						+							
Hyparrhenia filipendula	G	Terrestrial						+					+		
Impatiens nana	H	Catchment species				+									
Ipomoea pes- capreae	CL	Terrestrial			+			+			+	+			
Justicia betonica	H	Terrestrial	+												
Justicia glabra	H	Terrestrial							+						
Kanahia laniflora	H	Water loving plant		+								+	+		
Kigelia Africana	T	Terrestrial					+								
Krinum kirkii	H	Terrestrial													+
Kyllinga elata	SG	Aquatic plant	+												+
Lantana camara	S	Invasive species		+		+									
Launaea cornuta	H	Invasive species												+	
Lecaniodiscus fraxinifolius	T	Terrestrial					+		+						
Leersia hexandra	G	Aquatic plant										+			+
Leonotis mollissima	S	Terrestrial		+			+			+					
Leucaena glauca	T	Invasive species	+	+			+								
Ludwigia jussiaeoides	H	Aquatic plant								+				+	
Lycopercicon esculentum	H	Crop												+	
Mangifera indica	T	Invasive species							+				+		
Macrula africana	S	Terrestrial									+				
Manihot esculenta	S	Invasive species					+								
Markhamia lutea	T	Terrestrial	+			+									
Mascarenhasia arborescens	L	Terrestrial						+					+		
Maytenus mossambicensis	T	Terrestrial			+										
Maytenus senegalensis	S	Terrestrial				+									
Melanthera scandens	H	Terrestrial									+				
Mezoneuron angolense	L	Aquatic plant				+									
Mikania cordata	L	Water loving plant											+		+
Mimosa pigra	H	Water loving plant													+

Species name	Habit	Status	Site												
Mimusopsis fruticosa	T	Catchment species									+				
Mondia ecornuta	L	Terrestrial	+							+					
Mormodica foetida	L	Terrestrial	+		+										
Mucuna pruriens	L	Terrestrial											+		+
Musa spp.	CL	Terrestrial				+				+			+	+	
Nymphia retusa	H	Aquatic plant													+
Ormocarpum kirkii	S	Terrestrial											+		
Opilia celtidifolia	L	Crop								+					
Oplismenus hirtellus	G	Terrestrial	+						+						
Opuntia vulgaris	S	Drought loving plant					+								
Panicum maximum	G	Terrestrial					+	+		+		+			+
Panicum trichocladum	G	Terrestrial										+			
Parkia filicoidea	T	Terrestrial											+		
Paspalum scrobiculatum	G	Terrestrial											+		+
Passiflora edulis	CL	Terrestrial		+											
Paulllinia pinnata															+
Paveta stenocepala	S	Terrestrial	+												
Pennisetum mezianum	G	Terrestrial	+	+											
Pennisetum purpureum	G	Terrestrial				+								+	
Pergularia daemia	L	Terrestrial	+												
Phoenix reclinata	S	Terrestrial								+	+				+
Phragmites mauritianus	G	Aquatic	+							+	+	+		+	+
Pillaea adiantoides	CL	Terrestrial				+									
Plectranthus kilimandscharica	H	Terrestrial				+								+	
Pluchea dioscoridis	S	Terrestrial		+	+						+		+		
Polygonum senegalense	H	Aquatic plant	+					+						+	+
Prunus Africana	H	Terrestrial				+									
Psidium guavaja	S	Aquatic plant				+									
Psychotria riparia	S	Catchment species							+						
Rauvolfia caffra	T	Terrestrial	+	+		+	+			+					
Rhynchosia micrantha	CL	Terrestrial			+										
Ricinus communis	S	Invasive species		+									+	+	
Rinorea elliptica	S	Terrestrial									+				
Rothmannia urcelliformis	S	Terrestrial				+									
Rottboelia exaltata	G	Terrestrial											+		
Rubia cordifolia	CL	Terrestrial	+												
Rubus pinnatus	H	Terrestrial	+			+									
Rubus rosifolius	H	Terrestrial	+												
Saba comorensis	L	Terrestrial						+	+						
Saccharum officinarum	H	Terrestrial												+	
Salacia madagascariensis	L	Terrestrial							+						
Sansevieria ehrenbergii	H	Drought loving plant					+								
Sapindus saponaria	T	Terrestrial								+					
Sclerocarya birrea ssp.caffra	T	Terrestrial									+				
Sesbania sesbans	S	Water loving plant								+	+	+		+	+
Setaria homonyma	G	Terrestrial		+	+					+	+				
Sida cordifolia	H	Terrestrial				+									
Smilax anceps	CL	Terrestrial				+									
Solanecio angulatus	CL	Terrestrial				+									
Solanum incanum	H	Terrestrial		+	+										
Sorindeia madagascariensis	T	Catchment species				+		+	+						
Spermacoce laevis	H	Terrestrial	+												
Spilanthes filicaulis	H	Terrestrial	+												
Sporobolus concimilis	G	Terrestrial			+			+							

Species name	Habit	Status	Site												
Sporobolus pyramidalis	G	Terrestrial	+		+			+							+
Spyrostachys africana	T	Terrestrial									+				+
Stereospermum cunthianum	G	Terrestrial											+		
Strychnos cocculoides	L	Terrestrial				+									
Strychnos henningsii	T	Terrestrial					+								
Suaeda monoica	S	Salt loving plant			+										
Syzygium cumini	T	Terrestrial				+									+
Tabernaemontana holstii	S	Terrestrial							+						
Tabernaemontana pachysiphon	T	Catchment species		+											
Talinum portulacifolium	H	Terrestrial					+								
Teclea nobilis	S	Terrestrial					+								
Teclea simplicifolia	S	Terrestrial				+	+								
Thelypteris comfluens	FN	Catchment species	+			+									
Thespesia danis	S	Terrestrial											+		
Thevetia peruviana	F	Terrestrial											+		
Tithonia diversifolia	S	Catchment tree	+				+		+						
Toddalia asiatica	S	Terrestrial				+									
Trema orientalis	T	Terrestrial				+									
Trichilia emetica	S	Catchment species		+			+	+	+	+					
Trimeria grandifolia	T	Invasive species				+									
Turraea holstii	T	Terrestrial		+		+			+	+					
Typha capensis	RD	Terrestrial						+		+					
Urochloa panicoides	G	Terrestrial													+
Urtica massaica	H	Terrestrial			+										
Uvaria dependens	S	Terrestrial													
Uvaria scheffleri	S	Terrestrial					+								
Vangueria madagascariensis	H	Terrestrial		+		+	+		+						
Vernonia amygdalina	S	Terrestrial		+											
Vernonia hildebrandtii	S	Terrestrial								+					+
Vernonia subuligera	S	Terrestrial				+									
Vigna unguiculata	CL	Terrestrial											+		
Withania homnifera	H	Terrestrial		+											
Zea mays	S	Crop												+	
Ziziphus pubescens	T	Terrestrial					+								

APPENDIX E: Tentative checklist of the vascular plants recorded from the Pangani River Basin in the dry season

Acanthaceae
Asystasia gangetica
Justicia betonica
Justicia glabra

Adiantaceae
Acrostichum aureum
Pellaea adiantoides

Agavaceae
Agave sisalana
Sansevieria ehrenbergii

Aloaceae
Aloe lateritia

Amaranthaceae
Achyranthes aspera
Amaranthus hybridus

Anacardiaceae
Mangifera indica
Sclerocarya birrea ssp.caffra
Sorindeia madagascariensis

Annonaceae
Annona senegalensis
Uvaria dependens
Uvaria scheffleri

Apocynaceae
Mascarenhasia arborescens
Pergularia daemia
Rauvolfia caffra
Saba comorensis
Tabernaemontana holstii
Tabernaemontana pachysiphon
Thevetia peruviana

Araceae
Culcasia esculenta

Araliaceae
Cussonia arborea

Asclepiadaceae
Ceropergia distincta
Kanahia laniflora
Mondia ecornuta

Balsaminaceae
Impatiens nana

Bignoniaceae
Kigelia Africana
Markhamia lutea

Bignoniaceae
Stereospermum cunthianum

Bombacaceae
Bombax rhodognaphalon

Boraginaceae
Cordia abyssinica
Cordia sinensis
Ehretia amoena
Heliotropium indicum

Burseraceae
Commiphora pteleifolia

Cactaceae
Opuntia vulgaris

Caesalpiniaceae
Caesalpinia bonduc
Bauhinia tomentosa
Caesalpinia decapitala
Calanchoe prittwitzii
Cassia didymobotrya
Cassia floribunda
Cassia mimosoides
Cassia siamea
Cenna spectabilis
Mezoneuron angolense

Cannaceae
Canna indica

Capparidaceae
Boscia angustifolia

Caryophylaceae
Drymaria cordata

Celastraceae
Maytenus mossambicensis
Maytenus senegalensis
Salacia madagascariensis

Chenopodiaceae
Suaeda monoica

Combretaceae
Combretum pentagonum

Commelinaceae
Aneilema aequinoctiale
Commelina beghalensis

Compositae
Ageratum conyzoides
Bidens pilosa
Blumea aurita
Cenesio stuhlmannii
Galinsona parviflora
Launaea cornuta
Melanthera scandens

Mikania cordata
Pluchea dioscoridis
Solanecio angulatus
Spilanthes filicaulis
Tithonia diversifolia
Vernonia amygdalina
Vernonia hildebrandtii
Vernonia subuligera

Convolvulaceae
Astripomoea malvacea
Ipomoea pes- capreae

Cucurbitaceae
Mormodica foetida

Cyperaceae
Cyperus alticulatus
Cyperus distans
Cyperus exaltatus
Cyperus papyrus
Cyperus rotundus
Cyperus rotundus
Fimbristylis ferruginea
Kyllinga elata

Ebenaceae
Euclea natalensis

Euphorbiaceae
Acalypha ornata
Acalypha fruticosa
Antidesma venosum
Bridelia cathartica
Bridelia micrantha
Croton macrostachyus
Drypetes gerrardii
Drypetes natalensis
Erythroccocca bongensis
Euphorbia nyikae
Euphorbia tirucalli
Flueggea virosa
Manihot esculenta
Ricinus communis
Spyrostachys africana

Flacourtiaceae
Flacourtia indica
Trimeria grandifolia

Flagellariaceae
Flagellaria guineensis

Gramineae
Bambusa vulgaris
Brachiaria serrata
Chloris gayana
Cynodon dactylon
Cynodon nlemfuens
Dacyloctenium geminatum
Dichanthium caricosum
Digitaria milanjiana
Echnochloa scabra
Eragrostis aspera
Hyparrhenia filipendula
Leersia hexandra
Oplismenus hirtellus
Panicum maximum
Panicum trichocladum
Paspalum scrobiculatum
Pennisetum mezianum
Pennisetum purpureum
Phragmites mauritianus
Rottboelia exaltata
Saccharum officinarum
Setaria homonyma
Sporobolus concimilis
Sporobolus pyramidalis
Urochloa panicoides
Zea mays

Guttiferae
Garcinia livingstonei

Labiatae
Leonotis mollissima
Plectranthus kilimandscharica

Lecythidaceae
Barringtonia racemosa

Liliaceae
Krinum kirkii

Loganiaceae
Strychnos cocculoides
Strychnos henningsii

Malpighiaceae
Flabellaria paniculata

Malvaceae
Abutilon mauritianum
Hibiscus cannabinus
Hibiscus esculenta
Hibiscus micranthus
Sida cordifolia
Thespesia danis

Meliaceae
Azidarachta indica

Meliaceae
Trichilia emetica
Turraea holstii

Menispermaceae
Adenia rumicifolia
Cissampelos pereira

Mimosaceae
Acacia albida
Acacia brevispica
Acacia polyacantha
Acacia robusta
Acacia xanthophloea

Albizia glaberrima
Albizia gummifera
Albizia petersiana
Albizia schimperiana
Entada abyssinica
Leucaena glauca
Mimosa pigra
Parkia filicoidea
Nymphia retusa

Moraceae
Artocarpus integra
Ficus capreifolia
Ficus exasperata
Ficus sansibarica ssp.sansibarica
Ficus mucuso
Ficus sur
Ficus thonningii
Ficus vallis-choudae
Ficus ingens
Macrula africana

Musaceae
Musa spp.

Myrtaceae
Psidium guavaja
Syzygium cumini

Nyctaginaceae
Boerhavia repens

Nymphaceae
Sesbania sesbans

Onagraceae
Ludwigia jussiaeoides

Opiliaceae
Opilia celtidifolia

Palmae
Cocos nucifera
Elaeis guineensis
Phoenix reclinata

Papaveraceae
Argemone mexicana

Papilionaceae
Crotalaria laburnifolia
Dalbergia obovata
Desmodium repandum
Glycine wightii
Mucuna pruriens
Ormocarpum kirkii
Rhynchosia micrantha
Vigna unguiculata

Passifloraceae
Passiflora edulis

Polygonaceae
Polygonum senegalense

Portulaceae
Talinum portulacifolium

Proteaceae
Grevilea robusta

Rhamnaceae
Ziziphus pubescens

Rosaceae
Prunus Africana
Rubus pinnatus
Rubus rosifolius

Rubiaceae
Gardenia transvenulosa
Paveta stenocepala
Psychotria riparia
Rothmannia urcelliformis
Rubia cordifolia
Spermacoce laevis
Vangueria madagascariensis

Rutaceae
Cirtus limonia
Clausena anisata
Teclea nobilis
Teclea simplicifolia
Toddalia asiatica

Sapindaceae
Allophylus africanus
Haplocoelium foliolosum
Lecaniodiscus fraxinifolius
Paulllinia pinnata
Sapindus saponaria

Sapotaceae
Englerophytum natalense
Mimusopsis fruticosa

Simaroubaceae
Harrisonia abyssinica

Smilacaceae
Smilax anceps

Solanaceae
Cupsicum frutescens
Datura arborea
Lycopercicon esculentum
Solanum incanum
Withania homnifera

Thelypteridaceae
Thelypteris comfluens

Tiliaceae
Corchorus aestuans
Grewia conocarpa
Grewia mollis

Typhaceae
Typha capensis

Ulmaceae
Celtis africana
Chaetachme aristata
Trema orientalis

Urticaceae
Urtica massaica

Verbenaceae
Clerodendrum rotundifolia
Lantana camara

Violaceae
Rinorea elliptica

Vitaceae
Cissus cordifolia
Cissus intergrifolia
Cissus quandrangularis
Cissus rotundifolia

Zingberaceae
Costus afer

APPENDIX F: Environmental flow related questions for hydrology and hydraulics, channel morphology, water quality, invertebrates, fish and riparian vegetation

Hydrology and hydraulics

Site: R1

What is the overall flow pattern of the river (what months are the low flows, what month is the flood season(s)?
• Low flow season is from July to end of February or early March. • The flood season occurs in April and/or May.
How have flows changed in living memory (are floods getting bigger/smaller? Are there more or fewer? Is the dry season longer/shorter? Is/was the river perennial and what is the current situation?)
• There is no flood data for this site but the pattern might be similar to R2 site. • The dry season is longer. • The river is still perennial but low flow volumes have significantly reduced due to an increase in water use upstream.
Are any long-term flow changes causing differences in how and where water moves over the landscape (is the river deeper/shallower? Is flow faster/slower? Are floodplains still inundated or drying out? What percentage of floodplain/wetlands has disappeared? Are lakes changing - and how?).
• The geological formation at this site suggests that the depth of the river has not changed. • No floodplains near the site and no information is available on the status of nearby Lake Duluti.

Site: R2

What is the overall flow pattern of the river (what months are the low flows, what month is the flood season(s)?
• Low flow season is from July to August and/or early September (September to end of February or early March) - no flow at all in recent years. • The flood season occurs in April and/or May.
How have flows changed in living memory (are floods getting bigger/smaller? Are there more or fewer? Is the dry season longer/shorter? Is/was the river perennial and what is the current situation?)
• The floods are getting smaller in general but the number of floods does not seem to have changed. • The dry season is longer. • The river was perennial but it is no longer due to an increase in water use.
Are any long-term flow changes causing differences in how and where water moves over the landscape (is the river deeper/shallower? Is flow faster/slower? Are floodplains still inundated or drying out? What percentage of floodplain/wetlands has disappeared? Are lakes changing - and how?).
• Not enough information is available to tell if the depth of the river and flow rates has changed. • There are floodplains downstream of the site that are still inundated though less frequently - but there is no data about the percent of disappeared floodplains and the status of nearby Lake Duluti.

Site: R3

What is the overall flow pattern of the river (what months are the low flows, what month is the flood season(s)?
• Low flow season is from July to end of February or early March. • The flood season occurs in late April and/or May.
How have flows changed in living memory (are floods getting bigger/smaller? Are there more or fewer? Is the dry season longer/shorter? Is/was the river perennial and what is the current situation?)
• The floods do not appear too have changed significantly in terms of size and number. • The dry season is longer. • The river is perennial although this is sustained by the springs upstream (Chemka spring).
Are any long-term flow changes causing differences in how and where water moves over the landscape (is the river deeper/shallower? Is flow faster/slower? Are floodplains still inundated or

drying out? What percentage of floodplain/wetlands has disappeared? Are lakes changing - and how?).
• The depth and flow rates have not changed significantly. • The floodplains are still inundated though less frequently in the past decade. • There are no nearby natural lakes.

Site: R4

What is the overall flow pattern of the river (what months are the low flows, what month is the flood season(s)?
• Low flow season is from July to end of February or early March. • The flood season occurs in late April and/or early May.
How have flows changed in living memory (are floods getting bigger/smaller? Are there more or fewer? Is the dry season longer/shorter? Is/was the river perennial and what is the current situation?)
• There is no flood data for this site but the pattern might be similar to R5 site. • The dry season is longer. • The river is perennial.
Are any long-term flow changes causing differences in how and where water moves over the landscape (is the river deeper/shallower? Is flow faster/slower? Are floodplains still inundated or drying out? What percentage of floodplain/wetlands has disappeared? Are lakes changing - and how?).
• The geological formation at this site suggests that the depth of the river and the general shape of the channel have not changed. • No floodplains near the site and no lakes nearby.

Site: R5

What is the overall flow pattern of the river (what months are the low flows, what month is the flood season(s)?
• Low flow season is from July to end of February or early March. • The flood season occurs in late April and/or early May.
How have flows changed in living memory (are floods getting bigger/smaller? Are there more or fewer? Is the dry season longer/shorter? Is/was the river perennial and what is the current situation?)
• The flood sizes have not changed significantly but are slightly fewer especially in the past decade. • The dry season is longer. • The river is perennial but low flow significantly reduced due to upstream water use.
Are any long-term flow changes causing differences in how and where water moves over the landscape (is the river deeper/shallower? Is flow faster/slower? Are floodplains still inundated or drying out? What percentage of floodplain/wetlands has disappeared? Are lakes changing - and how?).
• No clear indication of change in depth of the river and the flow rates. • No floodplains near the site and no lakes nearby.

Site: R6

What is the overall flow pattern of the river (what months are the low flows, what month is the flood season(s)?
• Low flow season is from July to end of February or early March. • The flood season occurs in late April and/or early May.
How have flows changed in living memory (are floods getting bigger/smaller? Are there more or fewer? Is the dry season longer/shorter? Is/was the river perennial and what is the current situation?)
• There is no significant change to the flood sizes and numbers in this river. • The dry season is longer. • The river is perennial but low flow is largely sustained by outflow from lake Jipe.
Are any long-term flow changes causing differences in how and where water moves over the landscape (is the river deeper/shallower? Is flow faster/slower? Are floodplains still inundated or drying out? What percentage of floodplain/wetlands has disappeared? Are lakes changing - and how?).
• No indication of change in depth of the river and flow rates are more or less the same

• There is a wetland upstream of the site but no data is available on the percentage of disappeared part. Lake Jipe further upstream has experienced a decline in water level in the past decade.

Site: R8

What is the overall flow pattern of the river (what months are the low flows, what month is the flood season(s)?
• Flow is highly regulated through Nyumba ya Mungu Dam and there is no significant inflow between the site and Nyumba ya Mungu Dam.
How have flows changed in living memory (are floods getting bigger/smaller? Are there more or fewer? Is the dry season longer/shorter? Is/was the river perennial and what is the current situation?)
• Floods are held back at the reservoir and high flows observed are irregular. • The river is perennial with a more or less constant flow because of regulation.
Are any long-term flow changes causing differences in how and where water moves over the landscape (is the river deeper/shallower? Is flow faster/slower? Are floodplains still inundated or drying out? What percentage of floodplain/wetlands has disappeared? Are lakes changing - and how?).
• The depth is likely to have increased after the construction of NYM dam because sediment is mostly trapped upstream of the reservoir. • A large part of the floodplain has dried out. • No lakes nearby.

Site: R9

What is the overall flow pattern of the river (what months are the low flows, what month is the flood season(s)?
• Flow is highly regulated through Nyumba ya Mungu Dam and there is no significant inflow between the site and Nyumba ya Mungu Dam.
How have flows changed in living memory (are floods getting bigger/smaller? Are there more or fewer? Is the dry season longer/shorter? Is/was the river perennial and what is the current situation?)
• High flows seem to have no regular pattern (The incremental catchment is big but the area is very dry which means that no significant inflow) • The river is perennial and the flow is more or less constant because of regulation.
Are any long-term flow changes causing differences in how and where water moves over the landscape (is the river deeper/shallower? Is flow faster/slower? Are floodplains still inundated or drying out? What percentage of floodplain/wetlands has disappeared? Are lakes changing - and how?).
• The river depth is not likely to have changed at this site. • No floodplains and no lakes nearby.

Site: R10

What is the overall flow pattern of the river (what months are the low flows, what month is the flood season(s)?
• Flow is highly regulated through Nyumba ya Mungu Dam and another pool for hydropower production upstream of the site, although there is significant inflow between the site and Nyumba ya Mungu Dam especially during wet season.
How have flows changed in living memory (are floods getting bigger/smaller? Are there more or fewer? Is the dry season longer/shorter? Is/was the river perennial and what is the current situation?)
• Floods seem to have the normal pattern at this site - the sizes and number have not changed significantly. • The river is presumably perennial but sometimes dries out following abstraction for hydropower generation during low flows.
Are any long-term flow changes causing differences in how and where water moves over the landscape (is the river deeper/shallower? Is flow faster/slower? Are floodplains still inundated or drying out? What percentage of floodplain/wetlands has disappeared? Are lakes changing - and how?).
• The river depth has not changed. • No floodplains and no lakes nearby.

Site: R11

What is the overall flow pattern of the river (what months are the low flows, what month is the flood season(s)?
• Flow is highly regulated through Nyumba ya Mungu Dam and a further two pools for hydropower off take upstream of the site - there is significant inflow between the site and Nyumba ya Mungu Dam especially during wet season.
How have flows changed in living memory (are floods getting bigger/smaller? Are there more or fewer? Is the dry season longer/shorter? Is/was the river perennial and what is the current situation?)
• Flow depends on the release and spills from the Pangani Falls HP station. No data to tell about the nature of present high flows at this site, past flows should resemble river site R10. • The river is perennial though the natural river branch (Site R11A), which receives the spills is sometimes dry.
Are any long-term flow changes causing differences in how and where water moves over the landscape (is the river deeper/shallower? Is flow faster/slower? Are floodplains still inundated or drying out? What percentage of floodplain/wetlands has disappeared? Are lakes changing - and how?).
• The river depth is likely to have increased downstream of the confluence with the spill branch. • No floodplains and no lakes nearby.

Site: R12

What is the overall flow pattern of the river (what months are the low flows, what month is the flood season(s)?
• Low flow season is from July to early October and January to February • The flood season occurs from April to May and November to December
How have flows changed in living memory (are floods getting bigger/smaller? Are there more or fewer? Is the dry season longer/shorter? Is/was the river perennial and what is the current situation?)
• The number of floods has not changed significantly but the sizes have reduced due to the presence of medium sized reservoir upstream (Kalimawe Dam). • The river was perennial but in recent times often dries up during the dry season.
Are any long-term flow changes causing differences in how and where water moves over the landscape (is the river deeper/shallower? Is flow faster/slower? Are floodplains still inundated or drying out? What percentage of floodplain/wetlands has disappeared? Are lakes changing - and how?).
• There is no indication of change in depth of the river and the flow rates. • The floodplain is still inundated but not to the extent it used before, although there is no information on the extent of change of inundation. • There is a lake upstream but its status is not known.

Site: R13

What is the overall flow pattern of the river (what months are the low flows, what month is the flood season(s)?
• Low flow season is from July to February. • The flood season occurs from April to May.
How have flows changed in living memory (are floods getting bigger/smaller? Are there more or fewer? Is the dry season longer/shorter? Is/was the river perennial and what is the current situation?)
• The number of floods has not changed significantly but the sizes have reduced in the past 15 years. • The dry season is longer. • The river is still perennial though it dried up last year.
Are any long-term flow changes causing differences in how and where water moves over the landscape (is the river deeper/shallower? Is flow faster/slower? Are floodplains still inundated or drying out? What percentage of floodplain/wetlands has disappeared? Are lakes changing - and how?).
• There is no indication of change in depth of the river and the flow rates. • There is a floodplain at the site but no information on change of extent of inundation. • No lakes occur nearby.

Channel morphology

Site: R1

Is the shape and size of the channel changing, and if so, how? Since when?
• Changes, if any negligible
Is the nature of the river-bed changing - more/less rocks, sand, mud etc?
• No changes
Are stony beds scoured clean each year or are they silting up?
• There is water flow though out the year – stony beds do not appear to be silting up
Is the channel getting narrower, and if so, in what way?
• No changes at the site
Are there deep pools and are they being maintained?
• There are some pools, however not very deep
Are areas of turbulent rocky flow (i.e. riffles, rapids) being maintained?
• Yes

Site: R2

Is the shape and size of the channel changing, and if so, how? Since when?
• There are no obvious charges with regards to the shape and size of the channel
Is the nature of the river-bed changing - more/less rocks, sand, mud etc?
• There appears to be more gravel upstream
Are stony beds scoured clean each year or are they silting up?
• During flashy rains the stony beds silt up
Is the channel getting narrower, and if so, in what way?
• The channel is getting slightly wider due to human activities
Are there deep pools and are they being maintained?
• Yes, but further upstream – the pools are not maintained
Are areas of turbulent rocky flow (i.e. riffles, rapids) being maintained?
• Not maintained – there is only a very small patch of turbulent rocky flow at the site

Site: R3

Is the shape and size of the channel changing, and if so, how? Since when?
• This site is on the old channel after it has divided into two channels - the new channel has more water during low flow than this one (old). This happened in the late 1970's. The diversion was due to sedimentation/blockage of the channel.
Is the nature of the river-bed changing - more/less rocks, sand, mud etc?
• Negligible changes may be due to (small)slope
Are stony beds scoured clean each year or are they silting up?
• Yes, they are scoured each year
Is the channel getting narrower, and if so, in what way?
• Unknown – the dry season base flow was substantially less than the wet season base flow
Are there deep pools and are they being maintained?
• Yes, but during critical dry period they are not maintained
Are areas of turbulent rocky flow (i.e. riffles, rapids) being maintained?
• There are small areas of turbulent rocky flow during the low flow

Site: R4

Is the shape and size of the channel changing, and if so, how? Since when?
• No changes
Is the nature of the river-bed changing - more/less rocks, sand, mud etc?
• No changes
Are stony beds scoured clean each year or are they silting up?
• Scoured clean
Is the channel getting narrower, and if so, in what way?
• No
Are there deep pools and are they being maintained?
• Yes
Are areas of turbulent rocky flow (i.e. riffles, rapids) being maintained?
• Yes

Site: R5

Is the shape and size of the channel changing, and if so, how? Since when?
• There are slight changes due to human activities on the left side of the channel
Is the nature of the river-bed changing - more/less rocks, sand, mud etc?
• Yes, there is more sand and mud – there was substantial silt deposition on the river-bed during the dry season
Are stony beds scoured clean each year or are they silting up?
• The beds are slightly scoured - but remain muddy in places
Is the channel getting narrower, and if so, in what way?
• No, not apparent
Are there deep pools and are they being maintained?
• Yes
Are areas of turbulent rocky flow (i.e. riffles, rapids) being maintained?
• Yes

Site: R6

Is the shape and size of the channel changing, and if so, how? Since when?
• No changes
Is the nature of the river-bed changing - more/less rocks, sand, mud etc?
• Not much change
Are stony beds scoured clean each year or are they silting up?
• Stony beds are scarce – limited to an area at/under the bridge, probably artificial resulting from changes resulting from the bridge
Is the channel getting narrower, and if so, in what way?
• No apparent indications of the channel getting narrower
Are there deep pools and are they being maintained?
• Yes
Are areas of turbulent rocky flow (i.e. riffles, rapids) being maintained?
• Areas of turbulent flow not present at this site

Site: R7

Is the shape and size of the channel changing, and if so, how? Since when?
• Yes, more deposition since 1980's
Is the nature of the river-bed changing - more/less rocks, sand, mud etc?
• Yes, more sand and stones
Are stony beds scoured clean each year or are they silting up?
• Silting up
Is the channel getting narrower, and if so, in what way?
• Narrower towards the end due to sediment deposition
Are there deep pools and are they being maintained?
• It dries up each year, the pools are small and limited, most likely getting shallower due to sediment deposition
Are areas of turbulent rocky flow (i.e. riffles, rapids) being maintained?
• No

Site: R8

Is the shape and size of the channel changing, and if so, how? Since when?
• No flooding occurs due to Nyumba ya Mungu dam – long term changes on channel unknown although it does not appear to have changed
Is the nature of the river-bed changing - more/less rocks, sand, mud etc?
• No apparent changes; may be less deposition due to the dam
Are stony beds scoured clean each year or are they silting up?
• Stony beds not present at site
Is the channel getting narrower, and if so, in what way?
• No
Are there deep pools and are they being maintained?
• The channel is a homogenous and straight with no distinct "pools" - depth of the deep runs is likely to have increased due to the NYM dam
Are areas of turbulent rocky flow (i.e. riffles, rapids) being maintained?

• No areas of turbulent flow

Site: R9

Is the shape and size of the channel changing, and if so, how? Since when?
• No changes
Is the nature of the river-bed changing - more/less rocks, sand, mud etc?
• Bedrock dominates this site – no changes apparent
Are stony beds scoured clean each year or are they silting up?
• At some areas at the site they are scoured clean
Is the channel getting narrower, and if so, in what way?
• No
Are there deep pools and are they being maintained?
• Yes
Are areas of turbulent rocky flow (i.e. riffles, rapids) being maintained?
• Yes

Site: R10

Is the shape and size of the channel changing, and if so, how? Since when?
• There are no obvious changes – bedrock channel
Is the nature of the river-bed changing - more/less rocks, sand, mud etc?
• Bedrock dominates this site - stable rocks
Are stony beds scoured clean each year or are they silting up?
• Yes - water is released via the upstream hydropower diversion
Is the channel getting narrower, and if so, in what way?
• No
Are there deep pools and are they being maintained?
• Pools present at high and low flows – substantially shallower at low flows - depending of the operations of the HEP upstream
Are areas of turbulent rocky flow (i.e. riffles, rapids) being maintained?
• Bedrock – rapids present at high and low flows - dependent on the operations of the HEP upstream

Site: R11

Is the shape and size of the channel changing, and if so, how? Since when?
• No changes, though the velocity downstream increased due to the tailrace outflow
Is the nature of the river-bed changing - more/less rocks, sand, mud etc?
• Yes, less sand due to outflow from tailrace
Are stony beds scoured clean each year or are they silting up?
• No stony beds present
Is the channel getting narrower, and if so, in what way?
• No
Are there deep pools and are they being maintained?
• The channel is a homogenous and straight with no distinct "pools"
Are areas of turbulent rocky flow (i.e. riffles, rapids) being maintained?
• There are no areas of turbulent rocky flow

Site: R12

Is the shape and size of the channel changing, and if so, how? Since when?
• Yes, channel is changing depending on the season and the operation of the dam upstream and human activities in the area
Is the nature of the river-bed changing - more/less rocks, sand, mud etc?
• Yes, more sand
Are stony beds scoured clean each year or are they silting up?
• No stones at this site
Is the channel getting narrower, and if so, in what way?
• Yes since the 1970's
Are there deep pools and are they being maintained?
• There are no deep pools - at times you have "trickle flow" in the area or dry situation
Are areas of turbulent rocky flow (i.e. riffles, rapids) being maintained?

• No areas of turbulent flow

Site: R13

Is the shape and size of the channel changing, and if so, how? Since when?
• No apparent changes
Is the nature of the river-bed changing - more/less rocks, sand, mud etc?
• Yes, more silt
Are stony beds scoured clean each year or are they silting up?
• No stony beds at this site
Is the channel getting narrower, and if so, in what way?
• No
Are there deep pools and are they being maintained?
• Most of the time pools are maintained except in critical dry season
Are areas of turbulent rocky flow (i.e. riffles, rapids) being maintained?
• No areas of turbulent rocky flow at this site

Water quality

Site: R1

When is water quality best and worst, and how is this linked to wet/dry season?
• Dissolved oxygen (DO) concentration was lower in the dry season (8.2 to 6.5 mgl-1) • Total phosphorous (TP) was higher in the dry season (0.03 to 0.23 mgl-1) resulting in a trophic status shift from mesotrophic to eutrophic
Which variables are most sensitive to flow changes and how do they change under low flows and floods?
• Under low flows, temperature and nutrient loading may increase, while DO may decrease • Under flood conditions, turbidity and total suspended solids (TSS) may increase
Has water quality changed in living memory, and if so, how and (if known or suspected) why?
• No significant changes observed
Is the water more or less turbid than historically? Give details of when water is most turbid (e.g. beginning of flood season, first part of each storm, whenever it rains etc). Is turbidity mostly due to organic or inorganic material?
• No change in turbidity, values generally <10 NTUs

Site: R2

When is water quality best and worst, and how is this linked to wet/dry season?
• This site dries up during the dry season due extensive abstraction upstream • Turbidity is higher than expected for an upper foothill site (39 NTU) - lack of riparian vegetation and extensive livestock farming
Which variables are most sensitive to flow changes and how do they change under low flows and floods?
• Under low flows, temperature and nutrient loading may increase, while DO may decrease • Under flood conditions, turbidity and total suspended solids (TSS) may increase
Has water quality changed in living memory, and if so, how and (if known or suspected) why?
• Site used to be perennial, but no longer flows throughout the year - consequences for water quality
Is the water more or less turbid than historically? Give details of when water is most turbid (e.g. beginning of flood season, first part of each storm, whenever it rains etc). Is turbidity mostly due to organic or inorganic material?
• No historical data available, but turbidity is likely to have increased historically. Likely to be highest at the beginning of flood season - mostly inorganic.

Site: R3

When is water quality best and worst, and how is this linked to wet/dry season?
• Conductivity was higher in the dry season (50 to 140 mSm-1) - upstream runoff from the sugarcane plantations at TPC may contribute to these high values as well as the fact that the water is derived from the Chemka spring • Geologically this site has high levels of calcium and magnesium - under low flow conditions these become concentrated in the water. Bicarbonates increased from 126 to 776 mgl-1, calcium increased from 10 to 85 mgl-1and magnesium increased from 6 to 53 mgl-1 in the dry

season. • Total phosphorous (TP) was higher in the dry season (0.06 to 0.17 mgl-1); resulting in a trophic status shift from mesotrophic to eutrophic
Which variables are most sensitive to flow changes and how do they change under low flows and floods?
• Under low flows, temperature, conductivity and nutrient loading increases • Under flood conditions, turbidity and total suspended solids (TSS) may increase
Has water quality changed in living memory, and if so, how and (if known or suspected) why?
• Historically the amount of water would have been greater and therefore conductivity and calcium/magnesium levels would not have increased as much in the dry season • Increased localized use of the river for livestock watering and washing
Is the water more or less turbid than historically? Give details of when water is most turbid (e.g. beginning of flood season, first part of each storm, whenever it rains etc). Is turbidity mostly due to organic or inorganic material?
• No historical data available, but turbidity is likely to have increased historically. Likely to be highest at the beginning of flood season - mostly inorganic.

Site: R4

When is water quality best and worst, and how is this linked to wet/dry season?
• No apparent changes in water quality from wet to dry seasons
Which variables are most sensitive to flow changes and how do they change under low flows and floods?
• Under very low flows, temperature may increases, and DO may decrease
Has water quality changed in living memory, and if so, how and (if known or suspected) why?
• Unknown, but unlikely to have changed historically
Is the water more or less turbid than historically? Give details of when water is most turbid (e.g. beginning of flood season, first part of each storm, whenever it rains etc). Is turbidity mostly due to organic or inorganic material?
• Turbidity was low (< 4 NTU)

Site: R5

When is water quality best and worst, and how is this linked to wet/dry season?
• Increase in silt deposited on the riverbed during the dry season • Increased temperature during the dry season (18.3 to 24.5 oC) • Localised human use of the river - less water therefore impact may be greater in dry season • *E. coli* levels are likely to be higher in the wet season when they are introduced to the river from the surrounding land
Which variables are most sensitive to flow changes and how do they change under low flows and floods?
• Under low flows, temperature, nutrient loading increases, while DO may decrease • Under flood conditions, turbidity and total suspended solids (TSS) may increase
Has water quality changed in living memory, and if so, how and (if known or suspected) why?
• Increased human use of river (e.g. washing cars, bathing etc.) is likely to have modified the water quality
Is the water more or less turbid than historically? Give details of when water is most turbid (e.g. beginning of flood season, first part of each storm, whenever it rains etc). Is turbidity mostly due to organic or inorganic material?
• No historical data available, but turbidity levels generally < 15 NTU. Likely to be highest at the beginning of flood season - mostly inorganic.

Site: R6

When is water quality best and worst, and how is this linked to wet/dry season?
• Dissolved oxygen (DO) concentration were extremely low during the wet and dry season (<0.6 mgl-1) - upstream the river flows from lake Jipe through a swamp area with a large amount of decaying vegetation • Total phosphorous (TP) was higher in the dry season (0.06 to 0.15 mgl-1); resulting in a trophic status shift from mesotrophic to eutrophic • The aquatic macrophyte (*Azolla pinnata*) was only present in the dry season
Which variables are most sensitive to flow changes and how do they change under low flows and floods?

• Under low flows, temperature, nutrient loading increases, while DO may decrease • Under flood conditions, organic material may increase leading to further reductions in DO and possible increase in turbidity
Has water quality changed in living memory, and if so, how and (if known or suspected) why?
• Historically Lake Jipe was fed by rivers from Kenya and Tanzania - at some stage all water in rivers flowing from Kenya was abstracted resulting in a shrinking of Lake Jipe and encroachment of *Typha capensis.* In 2004 less water was abstracted from the Kenyan rivers and Lake Jipe filled up again. In 2005 this water was released causing a further drop in DO.
Is the water more or less turbid than historically? Give details of when water is most turbid (e.g. beginning of flood season, first part of each storm, whenever it rains etc). Is turbidity mostly due to organic or inorganic material?
• No historical data available, but turbidity levels likely to have increased due to reasons above. Most turbid in wet season, mainly organic material

Site: R7

When is water quality best and worst, and how is this linked to wet/dry season?
• The river is naturally seasonal and dries up each dry season • Water quality is likely to be at its worst just before the river dries up - extensive upstream abstraction during the wet season results in a shorter period of flow in the river • Turbidity and TSS are higher than expected for an upper foothill site (53 NTU, 71 mgl-1) - rainfall had occurred days before, which may have been the cause of this increase in turbidity
Which variables are most sensitive to flow changes and how do they change under low flows and floods?
• Under low flows, temperature may increase, while DO may decrease • Under flood conditions, turbidity and total suspended solids (TSS) may increase
Has water quality changed in living memory, and if so, how and (if known or suspected) why?
• Increased abstraction of water for human use of river has led to less water - may have water quality effects
Is the water more or less turbid than historically? Give details of when water is most turbid (e.g. beginning of flood season, first part of each storm, whenever it rains etc). Is turbidity mostly due to organic or inorganic material?
• No historical data available. Likely to be highest at the beginning of flood season - mostly inorganic.

Site: R8

When is water quality best and worst, and how is this linked to wet/dry season?
• This site is below NYM and thus water levels are determined by releases from the dam - more water is released during the dry season • Total phosphorous (TP) was higher in the dry season (0.03 to 0.23 mgl-1); resulting in a trophic status shift from mesotrophic to eutrophic - this may be due to bottom releases from the dam or the increased agriculture which occurs in the dry season (maize and vegetables)
Which variables are most sensitive to flow changes and how do they change under low flows and floods?
• No particular variables more sensitive to flow changes - large slow flowing river at this point.
Has water quality changed in living memory, and if so, how and (if known or suspected) why?
• No historical data but likely to have changed after the construction of NYM - Kirua swamp no longer flooded annually • The NYM is built on calcareous soils - very high levels of carbonates and bicarbonates are released from the dam, elevated levels continue into the mature lower river.
Is the water more or less turbid than historically? Give details of when water is most turbid (e.g. beginning of flood season, first part of each storm, whenever it rains etc). Is turbidity mostly due to organic or inorganic material?
• No historical data available - floods not released.

Site: R9

When is water quality best and worst, and how is this linked to wet/dry season?
• This site is below NYM and thus water levels are determined by releases from the dam and abstraction upstream • Total phosphorous (TP) was higher in the dry season (0.03 to 0.28 mgl-1); resulting in a trophic status shift from meso/eutrophic to hypertrophic - there are sisal plantations, cattle ranches and small-scale agriculture (within the riparian zone), which are likely to contribute to nutrient

enrichment
Which variables are most sensitive to flow changes and how do they change under low flows and floods?
• Under flood conditions, turbidity and nutrient loads may increase
Has water quality changed in living memory, and if so, how and (if known or suspected) why?
• No historical data but likely to have changed after the construction of NYM, increase in number of sisal plantations, livestock ranches and localized agriculture
Is the water more or less turbid than historically? Give details of when water is most turbid (e.g. beginning of flood season, first part of each storm, whenever it rains etc). Is turbidity mostly due to organic or inorganic material?
• No historical data available - floods not released.

Site: R10

When is water quality best and worst, and how is this linked to wet/dry season?
• This site is below NYM and thus water levels are determined by releases from the dam and abstraction upstream • Conductivity was higher in the dry season (49.9 to 69.8 mgl-1) • DO decreased from 6.9 to 6.4, but more in the slow flowing areas of the river • Nitrite was higher in the dry season (0.005 to 0.042 mgl-1) - nitrite is toxic at high concentrations • Total phosphorous (TP) was higher in the dry season (0.03 to 0.46 mgl-1); resulting in a trophic status shift from meso/eutrophic to hypertrophic - the town of Hale is close to this site, dumping of rubbish occurs within the riparian zone • *E. coli* levels are likely to be higher in the wet season when they are introduced to the river from the surrounding land
Which variables are most sensitive to flow changes and how do they change under low flows and floods?
• Under low flows, conductivity, temperature, nutrient loading increases, while DO may decrease • Floods no longer occur.
Has water quality changed in living memory, and if so, how and (if known or suspected) why?
• The town of Hale was built when the Pangani Falls hydropower station was built in the 1990s. This is likely to have resulted in changes in several water quality variables.
Is the water more or less turbid than historically? Give details of when water is most turbid (e.g. beginning of flood season, first part of each storm, whenever it rains etc). Is turbidity mostly due to organic or inorganic material?
• No historical data available - elevated turbidity is likely to occur at the beginning of the flood season - localised

Site: R11A

When is water quality best and worst, and how is this linked to wet/dry season?
• This site is below Hale Hydropower station and NYM thus water levels are determined by releases from NYM dam and abstraction upstream • Total phosphorous (TP) was higher in the dry season (0.02 to 0.43 mgl-1); resulting in a trophic status shift from meso/eutrophic to hypertrophic - the town of Hale is close to this site, dumping of rubbish occurs within the riparian zone
Which variables are most sensitive to flow changes and how do they change under low flows and floods?
• Under low flows, temperature, nutrient loading may increase, while DO may decrease • Floods no longer occur
Has water quality changed in living memory, and if so, how and (if known or suspected) why?
• The town of Hale was built when the Pangani Falls hydropower station was built in the 1990s. This is likely to have resulted in changes in several water quality variables.
Is the water more or less turbid than historically? Give details of when water is most turbid (e.g. beginning of flood season, first part of each storm, whenever it rains etc). Is turbidity mostly due to organic or inorganic material?
• No historical data available - elevated turbidity is likely to occur at the beginning of the flood season - localised

Site: R11

When is water quality best and worst, and how is this linked to wet/dry season?
• This site is below Pangani Falls Hydropower station and NYM thus water levels are determined

by releases from NYM dam and abstraction upstream. The site is intermittently dry during the dry season - approx. 8 hours in every 24 hours. • Turbidity levels are higher at R11 than the R11A (40 versus 20 NTU). • Nitrite was higher in the dry season (0.003 to 0.023 mgl-1) - nitrite is toxic at high concentrations
Which variables are most sensitive to flow changes and how do they change under low flows and floods?
• Low flows = no flow: water restricted to isolated pools, which are likely to have higher temperatures and lower DO • Floods no longer occur
Has water quality changed in living memory, and if so, how and (if known or suspected) why?
• Pangani Falls Hydropower Station was built in the 1990s. This is likely to have modified the downstream water quality, e.g. turbidity.
Is the water more or less turbid than historically? Give details of when water is most turbid (e.g. beginning of flood season, first part of each storm, whenever it rains etc). Is turbidity mostly due to organic or inorganic material?
• Yes, it is more turbid - turbidity increases whenever water is released, mostly inorganic

Site: R12

When is water quality best and worst, and how is this linked to wet/dry season?
• Conductivity was higher in the dry season (73 to 181 mSm-1). Extensive agriculture upstream of site, including sisal plantations, maize, beans, vegetables and rice - the entire floodplain is cultivated within and beyond the riparian zone. • DO decreased from 6.79 to 5.03 mgl-1 • Total phosphorous (TP) was higher in the dry season (0.04 to 0.12 mgl-1); resulting in a trophic status shift from mesotrophic to eutrophic • Sulphate was 172 mgl-1 in the wet season (the next highest value was at 60 mgl-1 R11) and 425 mgl-1 in the dry season (the next highest value was at 37 mgl-1 R11A).
Which variables are most sensitive to flow changes and how do they change under low flows and floods?
• Under low flows, temperature, conductivity, nutrient loading and sulphates may increase, while DO may decrease • Under flood conditions, turbidity, nutrient loads and sulphates may increase
Has water quality changed in living memory, and if so, how and (if known or suspected) why?
• No historical data but likely to have changed after the construction of Kalimawe and increase in number of agriculture
Is the water more or less turbid than historically? Give details of when water is most turbid (e.g. beginning of flood season, first part of each storm, whenever it rains etc). Is turbidity mostly due to organic or inorganic material?
• No historical data available - likely to be higher since farming activities are more extensive and closer to the river; and flows are less

Site: R13

When is water quality best and worst, and how is this linked to wet/dry season?
• Total nitrogen (TN) was higher in the wet season (3.86 to 0.44 mgl-1) - possibly as a result of farming activities in the surrounding area (sisal, maize, etc). • Total phosphorous (TP) was higher in the dry season (0.06 to 0.1 mgl-1); resulting in a trophic status shift from mesotrophic to eutrophic
Which variables are most sensitive to flow changes and how do they change under low flows and floods?
• Under low flows, temperature and nutrient loading may increase, while DO may decrease • Under flood conditions, turbidity and nutrient loads may increase
Has water quality changed in living memory, and if so, how and (if known or suspected) why?
• No historical data available - more agriculture in recent times
Is the water more or less turbid than historically? Give details of when water is most turbid (e.g. beginning of flood season, first part of each storm, whenever it rains etc). Is turbidity mostly due to organic or inorganic material?
• No historical data available

Aquatic invertebrates

General information for select aquatic invertebrate (based on existing knowledge)

Heptageniidae: Heptageniids are a characteristic family of upper foothill reaches of rivers. They are grazers feeding on periphyton and are considered to be very productive. Later instars have been observed to colonise shallow areas with lower velocities before emergence in spring. The body is flattened to facilitate clinging to stones in relatively swift flowing currents. The family is found mostly in riffle areas in fast flow. Estimates indicate that heptageniids require flows of 0.5 to 1.2 ms^{-1}. They may be susceptible to stranding during rapid reductions in flow.
Baetidae: Baetids are widespread and are mostly collector-gatherers feeding on detritus. Species occur in stones and vegetation with various types of flow.
Tricorythidae: Tricorythids are filter feeders and prefer stony biotopes, normally occurring on the underside of stones in moderate to swiftly flowing currents. In southern Africa, they are adversely affected by flow cessation or extremely low-flow stages - its lifecycle is synchronised so that adult emergence and egg-laying take place over a short period. Silt deposition appears to restrict their distribution.
Hydropsychidae: Hydropsychids construct and live in stout shelters to which a net is attached and in which plankton, detritus and small organisms are caught. Larvae are also predatious. They prefer large stable substrate and high current velocity, and are predominantly found in riffles, runs and cascades and require strong-flowing water to support their silken food-collecting nets. They have also been noted in aquatic vegetation in fast-flowing water.
Leptoceridae: Most leptocerids are omnivorous, fulfilling the functional role of collector-gatherers. Their cases are frequently constructed of sand grains, with larger pebbles used as “ballast” to anchor the larvae onto the substrate in moderate flows of water. They also walk amongst the vegetation and aquatic macrophytes, and some leptocerids have cases constructed of plant material. They occur in runs/riffles, SOOC and sand.
Elmidae: Elmids live under stones in fast to medium-flowing water and are called “riffle beetles” because they are most commonly associated with the riffle biotope. They also occur less frequently in other biotopes such as aquatic and marginal vegetation in fast-flowing water.
Athericidae: Athericids are normally recorded in mountain streams. Larvae are predators. They inhabit flowing water; with a preference for stony bottom biotopes such riffle and runs. They have also been recorded in SOOC.
Aeschnidae: Aeschnids are mostly opportunistic predators, feeding on a variety of prey including insect larvae, small crustaceans, oligochaetes, and sometimes small fish. They are generally found in stones in medium to fast flowing water.
Libellulidae: Libellulids are also mostly opportunistic predators. The adult female inserts her eggs into plant material or casts them onto the surface of the water. Larval developmental rate is determined by time of year, the prevailing temperature and food availability. Prior to emergence the larva climbs out of the water onto a rock, reed stem or bank. Libellulids have been recorded in stony habitats, both in- and out-of-current, and in vegetation.
Crambiidae: Crambiidae (butterfly) larvae feed on leaves near the surface of the water and are associated with aquatic vegetation, riffles and runs. Seasonal trends have been noted in South Africa - larvae are generally present in spring and summer only.
Coenagrionidae: Larvae prefer slow flowing areas of rivers and are often recorded in vegetation in backwaters, pools and slackwaters.
Caenidae: Caenid nymphs are often associated with conditions where there is little flow, such as backwaters, slackwaters and pools. They are often found among the silty substances of backwaters, or among aquatic vegetation, where they feed on fine particulate detritus and periphyton. Their bodies are often covered with fine detrital particles.
Ecnomidae: Very little is known about their ecology and feeding behaviour, although they are thought to be predatious. Species construct tubular shelters on the undersides of stones positioned in slow (to medium) flowing water.
Gomphidae: Gomphid larvae are predatious and are mostly recorded in sandy substrates where they burrow under the sand.

Site: R1

Can the invertebrate species be grouped into communities that occur in different kinds of flow conditions? What would these species groupings be and what flow conditions are linked to each (pattern of water flow: still, slow, smooth/gliding, medium-fast rippled, fast-turbulent; water depth: shallow, deep; substratum: mud, sand, gravel/pebble, cobble, boulder, bedrock);
• Stones/boulders in medium to fast flow - riffle/run: Baetidae (>2sp), Heptageniidae, Tricorythidae, Aeschnidae, Hydropsychidae, Psphenidae, Simuliidae

- Stones/boulders in medium flow - riffle/run: Libellulidae, Leptoceridae, Athericidae
- Stones/boulders in slow flow: Caenidae
- Vegetation in medium to fast flow: Libellulidae, Leptoceridae
- Vegetation in slow flow - backwaters, slackwaters: Coenagrioniidae, Corixidae, Naucoridae
- Sand - backwater, slackwater or pools: Gomphidae

What additional flow conditions do they need for life-cycle requirements (e.g spawning and migratory flows etc)?

- Unknown for this region although the following general remarks can be made:
- Heptageniids final instars are known elsewhere to emerge in spring - they colonise shallower areas with lower velocities
- Libellulids final instars crawl onto rocks or vegetation prior to emergence
- Tricorythids: adult emergence and egg-laying take place over a short period and they are thus very susceptible to low flows or cessation of flows.

Are any invertebrate groups changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.

- Psphenidae were absent in the dry season - cause unknown
- Coenagrionidae were absent in the dry season possible because of the reduction in marginal out of current

Site: R2

Can the invertebrate species be grouped into communities that occur in different kinds of flow conditions? What would these species groupings be and what flow conditions are linked to each (pattern of water flow: still, slow, smooth/gliding, medium-fast rippled, fast-turbulent; water depth: shallow, deep; substratum: mud, sand, gravel/pebble, cobble, boulder, bedrock);

- Stones/boulders in medium to fast flow - riffle/run: Heptageniidae, Hydropsychidae
- Stones/boulders in slow flow: Caenidae
- Vegetation in slow flow - backwaters, slackwaters: Coenagrioniidae, Belastomatidae, Corixidae, Naucoridae, Notonectidae
- Backwater areas or calm water surfaces: Gerridae, Hydrometridae, Veliidae

What additional flow conditions do they need for life-cycle requirements (e.g spawning and migratory flows etc)?

- Unknown

Are any invertebrate groups changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.

- All invertebrates families were absent as the river was dried up.

Site: R3

Can the invertebrate species be grouped into communities that occur in different kinds of flow conditions? What would these species groupings be and what flow conditions are linked to each (pattern of water flow: still, slow, smooth/gliding, medium-fast rippled, fast-turbulent; water depth: shallow, deep; substratum: mud, sand, gravel/pebble, cobble, boulder, bedrock);

- Stones/boulders in medium to fast flow - riffle/run: Baetidae (>2sp), Tricorythidae, Hydropsychidae, Elmidae, Simuliidae
- Stones/boulders in medium flow - riffle/run: Libellulidae
- Stones/boulders in slow flow: Corduliidae, Chlorocyphidae, Leptophlebiidae, Caenidae, Ecnomidae
- Vegetation in medium to fast flow: Libellulidae
- Vegetation in slow flow - backwaters, slackwaters: Coenagrioniidae, Belastomatidae, Corixidae, Naucoridae, Dytiscidae
- Backwater areas or calm water surfaces: Gerridae, Hydrometridae, Veliidae, Gyrinidae

What additional flow conditions do they need for life-cycle requirements (e.g spawning and migratory flows etc)?

- Unknown

Are any invertebrate groups changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.

- Only 2 species of Baetidae were recorded in the dry season, indicating a potential loss of sensitive species
- Some invertebrates associated with vegetation, which was not in contact with the water, were absent in the dry season, e.g. Coenagrionidae, Belastomatidae, Naucoridae and Dytiscidae
- Tricorythidae and Elmidae, which were only recorded in the dry season, may have been missed

during the wet season as it was impossible to sample the loose stones biotopes (pebbles and cobbles), due to high flows and water levels.

Site: R4

Can the invertebrate species be grouped into communities that occur in different kinds of flow conditions? What would these species groupings be and what flow conditions are linked to each (pattern of water flow: still, slow, smooth/gliding, medium-fast rippled, fast-turbulent; water depth: shallow, deep; substratum: mud, sand, gravel/pebble, cobble, boulder, bedrock);

- Stones/boulders in medium to fast flow - riffle/run: Baetidae (>2sp), Heptageniidae, Tricorythidae, Hydropsychidae, Elmidae, Psphenidae, Simuliidae
- Stones/boulders in medium flow - riffle/run: Libellulidae, Leptoceridae
- Stones/boulders in slow flow: Turbellaria, Caenidae, Leptophlebiidae
- Backwater areas or calm water surfaces: Veliidae

What additional flow conditions do they need for life-cycle requirements (e.g. spawning and migratory flows etc)?

- Unknown

Are any invertebrate groups changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.

- Unlikely, as water levels in the river are still providing a variety of biotopes for the invertebrates in the dry season

Site: R5

Can the invertebrate species be grouped into communities that occur in different kinds of flow conditions? What would these species groupings be and what flow conditions are linked to each (pattern of water flow: still, slow, smooth/gliding, medium-fast rippled, fast-turbulent; water depth: shallow, deep; substratum: mud, sand, gravel/pebble, cobble, boulder, bedrock);

- Stones/boulders in medium to fast flow - riffle/run: Baetidae (>2sp), Heptageniidae, Tricorythidae, Aeshnidae, Hydropsychidae, Simuliidae
- Stones/boulders in medium flow - riffle/run: Leptoceridae
- Stones/boulders in slow flow: Caenidae, Thiaridae
- Vegetation in slow flow - backwaters, slackwaters: Coenagrioniidae, Belastomatidae, Naucoridae, Dytiscidae, Ancylidae, and Planorbiidae
- Sand - backwater, slackwater or pools: Gomphidae
- Backwater areas or calm water surfaces: Veliidae

What additional flow conditions do they need for life-cycle requirements (e.g spawning and migratory flows etc)?

- Unknown

Are any invertebrate groups changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.

- Only 2 species of Baetidae were recorded in the dry season, indicating a potential loss of sensitive species
- Tricorythidae not recorded in dry season - may be related to decrease in flow; loss of stones in fast flow and increase in silt deposition, which Tricorythids are adverse to.
- Aeschnidae - absent during dry season; loss of fast flow stones clear of silt and algae
- Leptoceridae - increased siltation likely to restrict Leptocerids during low flows
- Some invertebrates associated with vegetation were absent during the dry season, e.g. Belastomatidae, Naucoridae
- An increase in algal cover on the stones and vegetation during the dry season may have been responsible for the presence of Ancylidae and Planorbiidae (grazers). Planorbiids are the host snail for bilharzia although the genus and species would need to be verified

Site: R6

Can the invertebrate species be grouped into communities that occur in different kinds of flow conditions? What would these species groupings be and what flow conditions are linked to each (pattern of water flow: still, slow, smooth/gliding, medium-fast rippled, fast-turbulent; water depth: shallow, deep; substratum: mud, sand, gravel/pebble, cobble, boulder, bedrock);

- Vegetation (marginal and aquatic- *Ceratophylllum demersum*) in slow to medium flow - backwaters, slackwaters and pools: Coenagrioniidae, Belastomatidae, Corixidae, Naucoridae, Nepidae, Pleidae, Dytiscidae, Lymnaiedae, Planorbiidae
- Backwater areas or calm water surfaces: Gerridae, Hydrometridae, Veliidae, Gyrinidae

What additional flow conditions do they need for life-cycle requirements (e.g spawning and migratory flows etc)?

- Unknown

Are any invertebrate groups changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.

- An increase in algal cover on the stones and vegetation during the dry season may have been responsible for the presence of Lymnaeidae and Planorbiidae (grazers??). Planorbiids are the host snail for bilharzia although the genus and species would need to be verified

Site: R7

Can the invertebrate species be grouped into communities that occur in different kinds of flow conditions? What would these species groupings be and what flow conditions are linked to each (pattern of water flow: still, slow, smooth/gliding, medium-fast rippled, fast-turbulent; water depth: shallow, deep; substratum: mud, sand, gravel/pebble, cobble, boulder, bedrock);

- Stones in medium to fast flow - riffle: Crambiidae, Hydropsychidae, Elmidae and Athericidae
- Gravel: Tabanidae

What additional flow conditions do they need for life-cycle requirements (e.g spawning and migratory flows etc)?

- Unknown

Are any invertebrate groups changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.

- All invertebrates families were absent as the river was dried up.

Site: R8

Can the invertebrate species be grouped into communities that occur in different kinds of flow conditions? What would these species groupings be and what flow conditions are linked to each (pattern of water flow: still, slow, smooth/gliding, medium-fast rippled, fast-turbulent; water depth: shallow, deep; substratum: mud, sand, gravel/pebble, cobble, boulder, bedrock);

- Vegetation in slow flow - backwaters, slackwaters and pools: Calopterygidae, Coenagrioniidae, Belastomatidae, Corixidae, Nepidae, Notonectidae,
- Backwater areas or calm water surfaces: Gerridae and Veliidae
- Artificial habitat - fish trap: Hydropsychidae and Simuliidae

What additional flow conditions do they need for life-cycle requirements (e.g spawning and migratory flows etc)?

- Unknown

Are any invertebrate groups changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.

- The aseasonality/reversed seasonality of this site, i.e. intermittently higher flows during the dry season compared to the wet season, may have an effect of the invertebrates, although it is unlikely to be ecologically significant unless water levels drop to where the marginal vegetation is no longer in contact with the water. This is the critical biotope at this site.

Site: R9

Can the invertebrate species be grouped into communities that occur in different kinds of flow conditions? What would these species groupings be and what flow conditions are linked to each (pattern of water flow: still, slow, smooth/gliding, medium-fast rippled, fast-turbulent; water depth: shallow, deep; substratum: mud, sand, gravel/pebble, cobble, boulder, bedrock);

- Stones/boulders in medium to fast flow - riffle/run: Tricorythidae, Hydropsychidae, Simuliidae
- Stones/boulders in medium flow - riffle/run: Leptoceridae
- Stones/boulders in slow flow: Caenidae
- Vegetation in medium flow: Crambiidae, Calopterygidae, Libellulidae, Leptoceridae
- Vegetation in slow flow - backwaters, slackwaters: Coenagrioniidae, Corixidae, Naucoridae and Dytiscidae
- Sand - backwater, slackwater or pools: Gomphidae
- Backwater areas or calm water surfaces: Veliidae

What additional flow conditions do they need for life-cycle requirements (e.g spawning and migratory flows etc)?

- Unknown

Are any invertebrate groups changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.

- Crambiidae were absent in the dry season - this may be related to seasonal lifecycle requirements, rather than flow.

Site: R10

Can the invertebrate species be grouped into communities that occur in different kinds of flow conditions? What would these species groupings be and what flow conditions are linked to each (pattern of water flow: still, slow, smooth/gliding, medium-fast rippled, fast-turbulent; water depth: shallow, deep; substratum: mud, sand, gravel/pebble, cobble, boulder, bedrock);
• Stones/boulders in medium to fast flow - riffle/run: Hydropsychidae, Simuliidae • Stones/boulders in slow flow: Caenidae, Tabanidae, Thiaridae • Vegetation in medium to slow flow: Calopterygidae, Coenagrioniidae, Libellulidae, Corixidae, Naucoridae, Notonectidae, Lymnaeidae, Vivparidae • Sand - backwater, slackwater or pools: Gomphidae • Backwater areas or calm water surfaces: Veliidae, Gyrinidae
What additional flow conditions do they need for life-cycle requirements (e.g spawning and migratory flows etc)?
• Unknown
Are any invertebrate groups changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.
• An increase in algal cover on the stones and vegetation during the dry season may have been responsible for the presence of Lymnaeidae and Viviparidae (grazers??) • The presence of Oligochaete (only recorded in the dry season) and Hirudinea (numbers greater in the dry season) indicates severe water quality impairment at this site, which is substantially worse during the dry season when discharge and water levels are lower.

Site: R11

Can the invertebrate species be grouped into communities that occur in different kinds of flow conditions? What would these species groupings be and what flow conditions are linked to each (pattern of water flow: still, slow, smooth/gliding, medium-fast rippled, fast-turbulent; water depth: shallow, deep; substratum: mud, sand, gravel/pebble, cobble, boulder, bedrock);
• Vegetation in slow, medium or fast flow: Atyidae • Vegetation in medium to slow flow: Belastomatidae, Corixidae, Notonectidae, Dytiscidae • Backwater areas or calm water surfaces: Veliidae
What additional flow conditions do they need for life-cycle requirements (e.g spawning and migratory flows etc)?
• Unknown
Are any invertebrate groups changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.
• An increase in taxa occurred in the dry season but these were either highly tolerant taxa (Oligochaetes) or air-breather (Corixidae, Notonectidae, Dytiscidae)

Site: R11A

Can the invertebrate species be grouped into communities that occur in different kinds of flow conditions? What would these species groupings be and what flow conditions are linked to each (pattern of water flow: still, slow, smooth/gliding, medium-fast rippled, fast-turbulent; water depth: shallow, deep; substratum: mud, sand, gravel/pebble, cobble, boulder, bedrock);
• Stones/boulders in medium to fast flow - riffle/run: Hydropsychidae • Stones (under rock crevices) - flow unknown: Palaemonidae • Stones/boulders in slow flow: Caenidae, Thiaridae • Vegetation in slow, medium or fast flow Atyidae • Vegetation in medium to slow flow: Coenagrioniidae, Libellulidae, Naucoridae, Notonectidae, Dytiscidae
What additional flow conditions do they need for life-cycle requirements (e.g spawning and migratory flows etc)?
• Unknown
Are any invertebrate groups changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.
• The number of invertebrates increased with decreasing flow - possibly as a result of the increase in algae and areas of quiet water (stones and vegetation).

Site: R12

Can the invertebrate species be grouped into communities that occur in different kinds of flow conditions? What would these species groupings be and what flow conditions are linked to each (pattern of water flow: still, slow, smooth/gliding, medium-fast rippled, fast-turbulent; water depth:

shallow, deep; substratum: mud, sand, gravel/pebble, cobble, boulder, bedrock);
• Vegetation in medium to slow flow: Caloptergygidae, Coenagrionidae, Libellulidae, Belastomatidae, Corixidae, Notonectidae, Dytiscidae, Thiaridae, Viviparidae • Sand/gravel - backwater, slackwater or pools: Gomphidae, Thiaridae • Backwater areas or calm water surfaces: Veliidae, Gyrinidae
What additional flow conditions do they need for life-cycle requirements (e.g spawning and migratory flows etc)?
• Unknown
Are any invertebrate groups changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.
• The reason for the increase in taxa during low flow conditions is unknown. Pesticides? Runoff during wet season rain events?

Site: R13

Can the invertebrate species be grouped into communities that occur in different kinds of flow conditions? What would these species groupings be and what flow conditions are linked to each (pattern of water flow: still, slow, smooth/gliding, medium-fast rippled, fast-turbulent; water depth: shallow, deep; substratum: mud, sand, gravel/pebble, cobble, boulder, bedrock);
• Vegetation in medium to slow flow: Coenagrionidae, Aeschnidae, Corduliidae, Libellulidae, Belastomatidae, Corixidae, Naucoridae, Dytiscidae, Notonectidae, Thiaridae, Viviparidae • Sand - backwater, slackwater or pools: Gomphidae, Thiaridae • Backwater areas or calm water surfaces: Hydrometridae, Veliidae, Gyrinidae
What additional flow conditions do they need for life-cycle requirements (e.g spawning and migratory flows etc)?
• Unknown
Are any invertebrate groups changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.
• No dragonfly larvae (Aeschnidae, Cordullidae or Libellulidae) were recorded in the dry season - this may be related to the reduction in water quality linked to a reduction in water quantity.

<u>Fish</u>

Site: R1

Can the fish species be grouped into communities that occur in different kinds of flow conditions? What would these species groupings be and what flow conditions are linked to each (pattern of water flow: still, slow, smooth/gliding, medium-fast rippled, fast-turbulent; water depth: shallow, deep; substratum: mud, sand, gravel/pebble, cobble, boulder, bedrock);
• pattern of water flow: fast-turbulent during both seasons • water depth: deep and shallow near the banks, no much changes between the seasons • substratum: bedrock and boulders
What additional flow conditions do they need for life-cycle requirements (e.g spawning and migratory flows etc)?
• None known
Are any fish groups changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.
• The only fish species found at this site *Garra dembeensis*

Site: R2

Can the fish species be grouped into communities that occur in different kinds of flow conditions? What would these species groupings be and what flow conditions are linked to each (pattern of water flow: still, slow, smooth/gliding, medium-fast rippled, fast-turbulent; water depth: shallow, deep; substratum: mud, sand, gravel/pebble, cobble, boulder, bedrock);
• pattern of water flow: fast flowing, with a pool • water depth: Large changes between the seasons - during dry season the river section was dry except for a small shallow pool • substratum: riverbed consisted of a mixture of pebbles and gravel in upper reaches and mud near the banks
What additional flow conditions do they need for life-cycle requirements (e.g spawning and migratory flows etc)?
• *Clarias gariepinus* is known to be a spawning migratory and therefore requires sufficient water in

the system to enable it reach suitable spawning sites, while and *Tilapia sparmani* also needs water around to enable it survive through the dry season.

Are any fish groups changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.

- Not known - site dry in dry season.

Site: R3

Can the fish species be grouped into communities that occur in different kinds of flow conditions? What would these species groupings be and what flow conditions are linked to each (pattern of water flow: still, slow, smooth/gliding, medium-fast rippled, fast-turbulent; water depth: shallow, deep; substratum: mud, sand, gravel/pebble, cobble, boulder, bedrock);

- Patterns of water flow: medium fast rippled
- Water depth: deep during wet season to shallow during dry season
- Substratum: rocky and sandy

What additional flow conditions do they need for life-cycle requirements (e.g spawning and migratory flows etc)?

- Migratory fish especially potamodromous *Labeo* sp usually need increased flow in the river to trigger their spawning migration.
- *Clarias* can survive the dry seasons but also needs water to migrate to favourable sites.
- There is sand substrate for *Tilapia* provided there is sufficient calm water.

Are any fish groups changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.

- At this site any negative flow changes are likely to affect the potamodromous fish species i.e. *Barbus oxyrhynchus*, *Labeo cylindricus* and *Clarias* sp., which need high flows to flood the swamp land and enable the fish access spawning sites in the floodplains.

Site: R4

Can the fish species be grouped into communities that occur in different kinds of flow conditions? What would these species groupings be and what flow conditions are linked to each (pattern of water flow: still, slow, smooth/gliding, medium-fast rippled, fast-turbulent; water depth: shallow, deep; substratum: mud, sand, gravel/pebble, cobble, boulder, bedrock);

- Pattern of water flow: fast-turbulent
- Water depth: deep to shallow
- Substratum: rocky and boulders

What additional flow conditions do they need for life-cycle requirements (e.g spawning and migratory flows etc)?

- None known

Are any fish groups changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.

- Cyprinids need higher flows so that they can migrate to suitable spawning habitats.
- *Brycinus sadleri* population in the wild is said to be declining - it is already classified as LC on the IUCN Red List.

Site: R5

Can the fish species be grouped into communities that occur in different kinds of flow conditions? What would these species groupings be and what flow conditions are linked to each (pattern of water flow: still, slow, smooth/gliding, medium-fast rippled, fast-turbulent; water depth: shallow, deep; substratum: mud, sand, gravel/pebble, cobble, boulder, bedrock);

- Flow conditions: medium to fast rippled
- Water depth: shallow to deep in the pool
- Substratum: boulders, cobble, gravel and sand

What additional flow conditions do they need for life-cycle requirements (e.g spawning and migratory flows etc)?

- *Clarias gariepinus* and *Labeo* are potamodromous and usually need increased flow in the river to trigger their spawning migration.

Are any fish groups changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.

- Any substantial negative changes in flow may affect all the fish species that synchronize their spawning activities with high water flows.

Site: R6

Can the fish species be grouped into communities that occur in different kinds of flow conditions? What would these species groupings be and what flow conditions are linked to each (pattern of water flow: still, slow, smooth/gliding, medium-fast rippled, fast-turbulent; water depth: shallow, deep; substratum: mud, sand, gravel/pebble, cobble, boulder, bedrock);
• Pattern of flow: smooth gliding • Water depth: shallow to deep during wet season • Substratum: rocky bed, gravel and sand
What additional flow conditions do they need for life-cycle requirements (e.g spawning and migratory flows etc)?
• Killifishes need water to enable their aestivating eggs to hatch in case drought conditions occur.
Are any fish groups changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.
• *Barbus toppini* and *Labeo* spp will be affected if water flow is greatly reduced because they need to migrate upstream for spawning. • Killifishes and *Clarias* spp. will be less affected because they can withstand drought in case of severe reduction of flow.

Site: R7

Can the fish species be grouped into communities that occur in different kinds of flow conditions? What would these species groupings be and what flow conditions are linked to each (pattern of water flow: still, slow, smooth/gliding, medium-fast rippled, fast-turbulent; water depth: shallow, deep; substratum: mud, sand, gravel/pebble, cobble, boulder, bedrock);
• pattern of water flow: slow • water depth: shallow but there was a slightly deeper pool • substratum: gravel
What additional flow conditions do they need for life-cycle requirements (e.g spawning and migratory flows etc)?
• The site has seasonal flow - water flow throughout the year is needed in order to have the fish move from downstream or Lake Jipe to upstream areas. Although no fish were caught at the site, local people reported that *Clarias* and *Tilapia* are caught downstream the site during high flow season.
Are any fish groups changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.
• Unknown – site is seasonal

Site: R8

Can the fish species be grouped into communities that occur in different kinds of flow conditions? What would these species groupings be and what flow conditions are linked to each (pattern of water flow: still, slow, smooth/gliding, medium-fast rippled, fast-turbulent; water depth: shallow, deep; substratum: mud, sand, gravel/pebble, cobble, boulder, bedrock);
• pattern of water flow: smooth/ gliding • water depth: deep • substratum: mixture of gravel, sand and muddy
What additional flow conditions do they need for life-cycle requirements (e.g spawning and migratory flows etc)?
• This site had a lot of water during both sampling occasions because of regulated discharge from Nyumba ya Mungu Dam upstream. A lot different fish of relatively big size were seen especially during the wet season. The water is sufficient for normal activities of fish. However, additional flow may be required for fish species (such as *Labeo* spp) that migrate laterally into the floodplain to spawn.
Are any fish groups changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.
• Increase in water flow is likely to favour potamodromous species (eg. *Barbus oxyrhynchus*), *B. toppini*, and *Brycinus sadleri*) which will migrate upstream or laterally into the floodplains to spawn (e.g. *Labeo* spp) and catadromous species (e.g. *Anguiila* sp) therefore enhancing reproductive success. • Extreme high floods may reduce the survival of pelagic eggs by sweeping them to unfavourable habitats (Welcome 1985) • A decrease in water could lead to decline in abundance of total spawners such as *Brycinus* spp and *Labeo* spp.

• Spawning success of phytophilous fishes such as *Oreochromis* (Tilapia) is affected by failure of floods (Dudley 1972) - thus any decrease in flows that prevent flooding will affect negatively of the abundance of *Tilapia* found in this section of the river. • Only few fish species such as *Clarias* sp. may be able to survive under conditions of very low water flows.

Site: R9

Can the fish species be grouped into communities that occur in different kinds of flow conditions? What would these species groupings be and what flow conditions are linked to each (pattern of water flow: still, slow, smooth/gliding, medium-fast rippled, fast-turbulent; water depth: shallow, deep; substratum: mud, sand, gravel/pebble, cobble, boulder, bedrock);
• pattern of water flow: medium fast rippled • water depth: deep • substratum: rocky/ boulder/sandy
What additional flow conditions do they need for life-cycle requirements (e.g spawning and migratory flows etc)?
• Four fish species (*Barbus oxyrhynchus, B. toppini, Clarias gariepinus,* and *Tilapia sparmani*) were caught at this site. • A further six different types of fish were reported by local fishers. • The flow conditions were suitable.
Are any fish groups changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.
• As for site R8.

Site: R10

Can the fish species be grouped into communities that occur in different kinds of flow conditions? What would these species groupings be and what flow conditions are linked to each (pattern of water flow: still, slow, smooth/gliding, medium-fast rippled, fast-turbulent; water depth: shallow, deep; substratum: mud, sand, gravel/pebble, cobble, boulder, bedrock);
• pattern of water flow: slow to medium fast rippled • Water depth: shallow • Substratum: bedrock
What additional flow conditions do they need for life-cycle requirements (e.g spawning and migratory flows etc)?
• During the wet season a mixture of fish adapted to both types of flow conditions were recorded. During low flow (dry) season no fish was caught partly due to deteriorated water conditions and lower flows. • Higher flows are needed to initiate spawning activities of some potamodromous fish species. • Other fish species (Killifishes and *Clarias)* can withstand reduced flow conditions.
Are any fish groups changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.
• Some of the fish species that are potamodromous (*Barbus* spp., *Brycinus sadleri* and *Labeo cylindricus*) are likely to be affected by such reduced flows of water which may interfere with their spawning activities and therefore can affect the success of their spawning activities. • In addition, water quality deterioration experienced at the site during dry season - is likely to affect fish.

Site: R11

Can the fish species be grouped into communities that occur in different kinds of flow conditions? What would these species groupings be and what flow conditions are linked to each (pattern of water flow: still, slow, smooth/gliding, medium-fast rippled, fast-turbulent; water depth: shallow, deep; substratum: mud, sand, gravel/pebble, cobble, boulder, bedrock);
• Pattern of water flow: fast smooth/gliding below the tail race • Water depth: varied from deep during wet season to completely dry during dry season when the power station was shut down to enable power rationing • substratum: gravel
What additional flow conditions do they need for life-cycle requirements (e.g spawning and migratory flows etc)?
• The site had a number of fish species including estuarine species such as the gobbies, ambassids, milkfish, as well as freshwater species. Most estuarine fish (eg. *Glossogobius reichii, G. biocellatus*, *Abasis unitaenia*, *Chanos chanos*) breed in the freshwater environment and then

migrate towards the estuary. Inadequate flows will impede this migration.

- Elevated flow conditions are needed for inundating some vegetation to provide suitable spawning sites for *Synodontis nigromaculatus* in the floodplain.

Are any fish groups changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.

- Decline in flow changes as witnessed during the dry season survey will undoubtedly affect the distribution of the fish because water was being released from the hydropower station into the river intermittently leaving the river without any water for prolonged periods of time.

Site: R11a

Can the fish species be grouped into communities that occur in different kinds of flow conditions? What would these species groupings be and what flow conditions are linked to each (pattern of water flow: still, slow, smooth/gliding, medium-fast rippled, fast-turbulent; water depth: shallow, deep; substratum: mud, sand, gravel/pebble, cobble, boulder, bedrock);

- pattern of water flow: medium-fast rippled
- water depth: shallow
- substratum: bedrock and gravel

What additional flow conditions do they need for life-cycle requirements (e.g spawning and migratory flows etc)?

- This site is the old river channel but now consists of a channel receiving water spilled over from the head pond of the hydropower station. The very little water that was flowing supported the goby (*Glossogobius biocellatus)* and an eel (*Anguilla bicolor bicolor*).
- The gobby is an amphidromous fish spending appreciable amount of time in both the river and ocean in its life time, while the eel is an obligatory catadromous fish that grows out in the river but migrates to sea for spawning. Therefore, the presence of water in the system is very crucial for survival and reproduction of these two fish species.
- Any prolonged reduction in flow which may render some pools dry could be detrimental to the life cycle of these fish.

Are any fish groups changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.

- It is most likely that any prolonged drought that may affect river flow may affect negatively the abundance of the fish because it will interfere with breeding activities.

Site: R12

Can the fish species be grouped into communities that occur in different kinds of flow conditions? What would these species groupings be and what flow conditions are linked to each (pattern of water flow: still, slow, smooth/gliding, medium-fast rippled, fast-turbulent; water depth: shallow, deep; substratum: mud, sand, gravel/pebble, cobble, boulder, bedrock);

- pattern of water flow: slow
- water depth: shallow,
- substratum: mud, sand

What additional flow conditions do they need for life-cycle requirements (e.g spawning and migratory flows etc)?

- Seven fish species were recorded from this site. Some of the species (e.g. *Labeo cyclindricus, Barbus jacksonii, B. unitaenia, Brycinus sadleri*) are potaodromous; migrating upstream or laterally into floodplains for spawning. Therefore, higher flow conditions are needed to enable the fish to move to suitable spawning sites.
- The remaining fish species spawn within the stream provided right kind of habitats are available. *Tilapia* needs a sandy river bed where they can construct nests. Such a habitat is available Mkomazi River, whereas *Synodontis* sp. may need increased river flow to inundate the riparian vegetation to provide suitable spawning habitats.

Are any fish groups changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.

- Reduced flows may largely affect the abundance of potamodromous fish species (*Labeo cyclindricus, Barbus jacksonii, B. unitaenia, Brycinus sadleri)* through failure in spawning.

Site: R13

Can the fish species be grouped into communities that occur in different kinds of flow conditions? What would these species groupings be and what flow conditions are linked to each (pattern of water flow: still, slow, smooth/gliding, medium-fast rippled, fast-turbulent; water depth: shallow, deep; substratum: mud, sand, gravel/pebble, cobble, boulder, bedrock);

• pattern of water flow: slow • water depth: shallow • substratum: mud, sand
What additional flow conditions do they need for life-cycle requirements (e.g spawning and migratory flows etc)?
• Six fish species were identified at this site, including potamodromous species such as *Barbus toppini, B. unitaenia, Brycinus sadleri, Rhabdalestes* spp. and *Labeo* spp., which usually need increased flow in the river to trigger their upstream and lateral spawning migration. • *Clarias* spp. need inundated vegetation as a spawning substratum, a condition which also requires an increase in the river flow.
Are any fish groups changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.
• Changes in flow conditions, especially a decrease in flow, may negatively affect the abundance of potamodromous species that need floods to enable them move laterally into the floodplain to spawn. • The abundance of catfish may be affected under minimum flow conditions because they also need inundated vegetation as a breeding substrate.

Riparian vegetation

Site: R1

Is there natural riparian vegetation on the banks (i.e. species that are characteristic of river banks or wetlands and not found elsewhere)?
• Yes, there is natural vegetation on the banks and the following plant species is characteristic of riverbanks or wetlands *Phragmites mauritianus* (reed grass, riverbank species).
Does this vegetation show a zonation into different communities up the bank from water's edge to highest flood level? Can this zonation be described/characterized in any way (e.g. sedges, reeds, trees etc - and where is each community?)
• Yes, the vegetation type is mixture of trees and shrubs. Tree layer at the top canopy (5 to 30m tall) and layer of shrubs on the ground (1 to 5 m tall).
Can any of these vegetation communities be linked to different flow conditions (e.g. do locals know that floods reach a certain level of vegetation every year, or other vegetation levels only in very wet years etc)?
• Unknown
Are there plants in the water - either floating, emerging from the water or submerged? Are these indigenous or alien species? What hydraulic (depth, velocity, substratum) conditions are they in why do you think they are where they are?
• Yes, there such plants such as *Phragmites mauritianus e*merging from water rooting in the mud
Are any vegetation components changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.
Unknown - only one season data collected

Site: R2

Is there natural riparian vegetation on the banks (i.e. species that are characteristic of river banks or wetlands and not found elsewhere)?
• Yes, *Ficus capreifolia, which is* a riverbank species
Does this vegetation show a zonation into different communities up the bank from water's edge to highest flood level? Can this zonation be described/characterized in any way (e.g. sedges, reeds, trees etc - and where is each community?)
• Yes, trees vegetation type
Can any of these vegetation communities be linked to different flow conditions (e.g. do locals know that floods reach a certain level of vegetation every year, or other vegetation levels only in very wet years etc)?
• Unknown
Are there plants in the water - either floating, emerging from the water or submerged? Are these indigenous or alien species? What hydraulic (depth, velocity, substratum) conditions are they in why do you think they are where they are?
• No
Are any vegetation components changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.

• Unknown - only one season data collected

Site: R3

Is there natural riparian vegetation on the banks (i.e. species that are characteristic of river banks or wetlands and not found elsewhere)?
• Yes, *Acacia xanthophloes* and *Dactyloctenium geminatum* - both occur in seasonal flooded areas
Does this vegetation show a zonation into different communities up the bank from water's edge to highest flood level? Can this zonation be described/characterized in any way (e.g. sedges, reeds, trees etc - and where is each community?)
• Yes, mixture of trees and grasses
Can any of these vegetation communities be linked to different flow conditions (e.g. do locals know that floods reach a certain level of vegetation every year, or other vegetation levels only in very wet years etc)?
• Unknown
Are there plants in the water - either floating, emerging from the water or submerged? Are these indigenous or alien species? What hydraulic (depth, velocity, substratum) conditions are they in why do you think they are where they are?
• Yes, *Acacia xanthophloes* - submerged in the water
Are any vegetation components changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.
• Unknown - only one season data collected

Site: R4

Is there natural riparian vegetation on the banks (i.e. species that are characteristic of river banks or wetlands and not found elsewhere)?
• Yes, there is natural vegetation but no special plant species
Does this vegetation show a zonation into different communities up the bank from water's edge to highest flood level? Can this zonation be described/characterized in any way (e.g. sedges, reeds, trees etc - and where is each community?)
• Yes, mixture of trees and shrubs
Can any of these vegetation communities be linked to different flow conditions (e.g. do locals know that floods reach a certain level of vegetation every year, or other vegetation levels only in very wet years etc)?
• Unknown
Are there plants in the water - either floating, emerging from the water or submerged? Are these indigenous or alien species? What hydraulic (depth, velocity, substratum) conditions are they in why do you think they are where they are?
• No
Are any vegetation components changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.
• Unknown - only one season data collected

Site: R5

Is there natural riparian vegetation on the banks (i.e. species that are characteristic of river banks or wetlands and not found elsewhere)?
• Yes, there is natural vegetation but no special plant species
Does this vegetation show a zonation into different communities up the bank from water's edge to highest flood level? Can this zonation be described/characterized in any way (e.g. sedges, reeds, trees etc - and where is each community?)
• Yes, mixture of trees and shrubs
Can any of these vegetation communities be linked to different flow conditions (e.g. do locals know that floods reach a certain level of vegetation every year, or other vegetation levels only in very wet years etc)?
• Unknown
Are there plants in the water - either floating, emerging from the water or submerged? Are these indigenous or alien species? What hydraulic (depth, velocity, substratum) conditions are they in why do you think they are where they are?
• No
Are any vegetation components changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.

• Unknown - only one season data collected

Site: R6

Is there natural riparian vegetation on the banks (i.e. species that are characteristic of river banks or wetlands and not found elsewhere)?
• Yes, *Cyperus alticulatus; Cyperus exaltatus; Cyperus distans* (Papyrus, plant emerging from water rooting in the mud, wetland plant), *Typha capensis* (Bulrush, reeds - wetland plant)
Does this vegetation show a zonation into different communities up the bank from water's edge to highest flood level? Can this zonation be described/characterized in any way (e.g. sedges, reeds, trees etc - and where is each community?)
• Yes, mixture of trees and grasses
Can any of these vegetation communities be linked to different flow conditions (e.g. do locals know that floods reach a certain level of vegetation every year, or other vegetation levels only in very wet years etc)?
• Unknown
Are there plants in the water - either floating, emerging from the water or submerged? Are these indigenous or alien species? What hydraulic (depth, velocity, substratum) conditions are they in why do you think they are where they are?
• Yes, there are indigenous plants emerging from water rooting in the mud, including *Cyperus alticulatus; Cyperus exaltatus; Cyperus distans; Typha capensis*
Are any vegetation components changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.
• Unknown - only one season data collected

Site: R7

Is there natural riparian vegetation on the banks (i.e. species that are characteristic of river banks or wetlands and not found elsewhere)?
• Yes, there is natural vegetation but no special plant species
Does this vegetation show a zonation into different communities up the bank from water's edge to highest flood level? Can this zonation be described/characterized in any way (e.g. sedges, reeds, trees etc - and where is each community?)
• Only trees
Can any of these vegetation communities be linked to different flow conditions (e.g. do locals know that floods reach a certain level of vegetation every year, or other vegetation levels only in very wet years etc)?
• Unknown
Are there plants in the water - either floating, emerging from the water or submerged? Are these indigenous or alien species? What hydraulic (depth, velocity, substratum) conditions are they in why do you think they are where they are?
• No
Are any vegetation components changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.
• Unknown - only one season data collected

Site: R8

Is there natural riparian vegetation on the banks (i.e. species that are characteristic of river banks or wetlands and not found elsewhere)?
• Yes, *Typha capensis*; *Phragmites mauritianus*; *Cyperus exaltatus* and *Ludwigia jussiaeoides* (Water primrose, wetland plant)
Does this vegetation show a zonation into different communities up the bank from water's edge to highest flood level? Can this zonation be described/characterized in any way (e.g. sedges, reeds, trees etc - and where is each community?)
• Yes, mixture of sedges and reeds
Can any of these vegetation communities be linked to different flow conditions (e.g. do locals know that floods reach a certain level of vegetation every year, or other vegetation levels only in very wet years etc)?
• Unknown
Are there plants in the water - either floating, emerging from the water or submerged? Are these indigenous or alien species? What hydraulic (depth, velocity, substratum) conditions are they in why do you think they are where they are?
• The following plants are emerging from water rooting in the mud: *Typha capensis-*

• *Phragmites mauritianus ; Cyperus exaltatu ; Ludwigia jussiaeoides*
Are any vegetation components changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.
• Unknown - only one season data collected

Site: R9

Is there natural riparian vegetation on the banks (i.e. species that are characteristic of river banks or wetlands and not found elsewhere)?
• Yes, *Phragmites mauritianus; Cyperus exaltatus; Ludwigia jussiaeoides*
Does this vegetation show a zonation into different communities up the bank from water's edge to highest flood level? Can this zonation be described/characterized in any way (e.g. sedges, reeds, trees etc - and where is each community?)
• Yes, mixture of sedges and reeds
Can any of these vegetation communities be linked to different flow conditions (e.g. do locals know that floods reach a certain level of vegetation every year, or other vegetation levels only in very wet years etc)?
• Unknown
Are there plants in the water - either floating, emerging from the water or submerged? Are these indigenous or alien species? What hydraulic (depth, velocity, substratum) conditions are they in why do you think they are where they are?
• The following plants are emerging from water rooting in the mud: *Phragmites mauritianus; Cyperus exaltatus; Ludwigia jussiaeoides*
Are any vegetation components changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.
• Unknown - only one season data collected

Site: R10

Is there natural riparian vegetation on the banks (i.e. species that are characteristic of river banks or wetlands and not found elsewhere)?
Yes, *Phragmites mauritianus; Cyperus exaltatus; Ludwigia jussiaeoides; Pistia stratiotes* (Water lettuce, free-floating, water loving plant); *Eichhornia crassipes* (Water hyacinth, free-floating, water loving plant)
Does this vegetation show a zonation into different communities up the bank from water's edge to highest flood level? Can this zonation be described/characterized in any way (e.g. sedges, reeds, trees etc - and where is each community?)
• Yes, mixture of sedges and reeds
Can any of these vegetation communities be linked to different flow conditions (e.g. do locals know that floods reach a certain level of vegetation every year, or other vegetation levels only in very wet years etc)?
• Unknown
Are there plants in the water - either floating, emerging from the water or submerged? Are these indigenous or alien species? What hydraulic (depth, velocity, substratum) conditions are they in why do you think they are where they are?
• Yes, plants emerging from water rooting in the mud include: Phragmites mauritianus; *Cyperus exaltatus*; *Ludwigia jussiaeoides* • Plants floating in the water: *Pistia stratiotes*; *Eichhornia crassipes*
Are any vegetation components changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.
• Unknown - only one season data collected

Site: R11

Is there natural riparian vegetation on the banks (i.e. species that are characteristic of river banks or wetlands and not found elsewhere)?
• Yes, *Ficus capreifolia* - riverbank species
Does this vegetation show a zonation into different communities up the bank from water's edge to highest flood level? Can this zonation be described/characterized in any way (e.g. sedges, reeds, trees etc - and where is each community?)
• Yes, mixture of trees and grasses vegetation type
Can any of these vegetation communities be linked to different flow conditions (e.g. do locals know that floods reach a certain level of vegetation every year, or other vegetation levels only in very wet years etc)?

• Unknown
Are there plants in the water - either floating, emerging from the water or submerged? Are these indigenous or alien species? What hydraulic (depth, velocity, substratum) conditions are they in why do you think they are where they are?
• No
Are any vegetation components changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.
• Unknown - only one season data collected

Site: R12

Is there natural riparian vegetation on the banks (i.e. species that are characteristic of river banks or wetlands and not found elsewhere)?
• No, very few scattered natural species of *Ludwigia* and *Phragmites*
Does this vegetation show a zonation into different communities up the bank from water's edge to highest flood level? Can this zonation be described/characterized in any way (e.g. sedges, reeds, trees etc - and where is each community?)
• No
Can any of these vegetation communities be linked to different flow conditions (e.g. do locals know that floods reach a certain level of vegetation every year, or other vegetation levels only in very wet years etc)?
• Unknown
Are there plants in the water - either floating, emerging from the water or submerged? Are these indigenous or alien species? What hydraulic (depth, velocity, substratum) conditions are they in why do you think they are where they are?
• No
Are any vegetation components changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.
• Unknown - only one season data collected

Site: R13

Is there natural riparian vegetation on the banks (i.e. species that are characteristic of river banks or wetlands and not found elsewhere)?
• Yes, *Cyperus exaltatus*; *Pistia stratiotes*; *Nymphaea retusa* (Water lily, water loving plant)
Does this vegetation show a zonation into different communities up the bank from water's edge to highest flood level? Can this zonation be described/characterized in any way (e.g. sedges, reeds, trees etc - and where is each community?)
• Yes, mixture of trees, sedges and grasses
Can any of these vegetation communities be linked to different flow conditions (e.g. do locals know that floods reach a certain level of vegetation every year, or other vegetation levels only in very wet years etc)?
• Unknown
Are there plants in the water - either floating, emerging from the water or submerged? Are these indigenous or alien species? What hydraulic (depth, velocity, substratum) conditions are they in why do you think they are where they are?
• Yes, plants emerging from water rooting in the mud include Phragmites mauritianus; *Cyperus exaltatus*; *Ludwigia jussiaeoides*; *Nymphaea retusa* • Plants floating in the water include *Pistia stratiotes*; *Eichhornia crassipes*
Are any vegetation components changing in distribution/condition/abundance in a way that might be due to flow changes - describe as best as you can.
• Unknown - only one season data collected