



SOURCE TO SEA: TRACING CAUSES OF WATER QUALITY PROBLEMS AND EVALUATING POTENTIAL MITIGATION OPTIONS. CASE STUDY OF UMNGENI RIVER, SOUTH AFRICA

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1 Background

1.1 Objectives

This report summarizes efforts completed during bilateral collaboration “Source to Sea: uMngeni River, South Afrika” between Sweden represented by SMHI and HaV and South Africa represented by University of KwaZulu-Natal and Durban University of Technology. This collaboration started in 2016 with an objective to produce advanced decision-support for efficient reduction of water pollution.

The greater uMngeni catchment is under severe stress to supply the demand. Water is already brought in from other near-by catchments to provide additional volume needed by the water users and additional transfer schemes are being implemented and/or considered. Drought conditions were experienced in 2014 and continued through 2016. Raw water quality issues exacerbate the situation.

Upstream of the Durban Bay the water reservoirs are eutrophic, mainly due to nutrient emissions from agricultural activities and scattered settlements. Agriculture causes effluents from livestock production as well as leaching of nutrients from crop growing areas. Erosion and sediment loss is an associated concern and there is thus need for a strong focus on impacts of land use in the upper part of catchment. Further downstream, the water quality issues are driven by sanitation and pollution problems from the cities of Pietermaritzburg and Durban.

The water quality in these urban areas close to the coast is affected by the insufficient and overloaded systems, causing emissions of pathogens and antibiotics to the water system. This has led to problems with using water for bathing and drinking.

This study utilizes the HYPE model <http://hype.sourceforge.net/> developed by the SMHI. The model can quantify the impact from various sources to polluted waterbodies and also distinguish between natural and anthropogenic influence. During 2016, the model was set up and calibrated for the uMngeni River basin and surrounding basins.

1.2 Study Area Description

The uMngeni River catchment is 4000 km² (Fig. 1.) and managed as part of the water district ‘Greater uMngeni’ also including the Mooi and Mkomazi Rivers. They all have their origin in the KZN Drakensberg and its foothills, and are eastern flowing systems which drain into the Indian Ocean. Together they are utilized to provide water to the cities of Pietermaritzburg and Durban and surrounding areas.

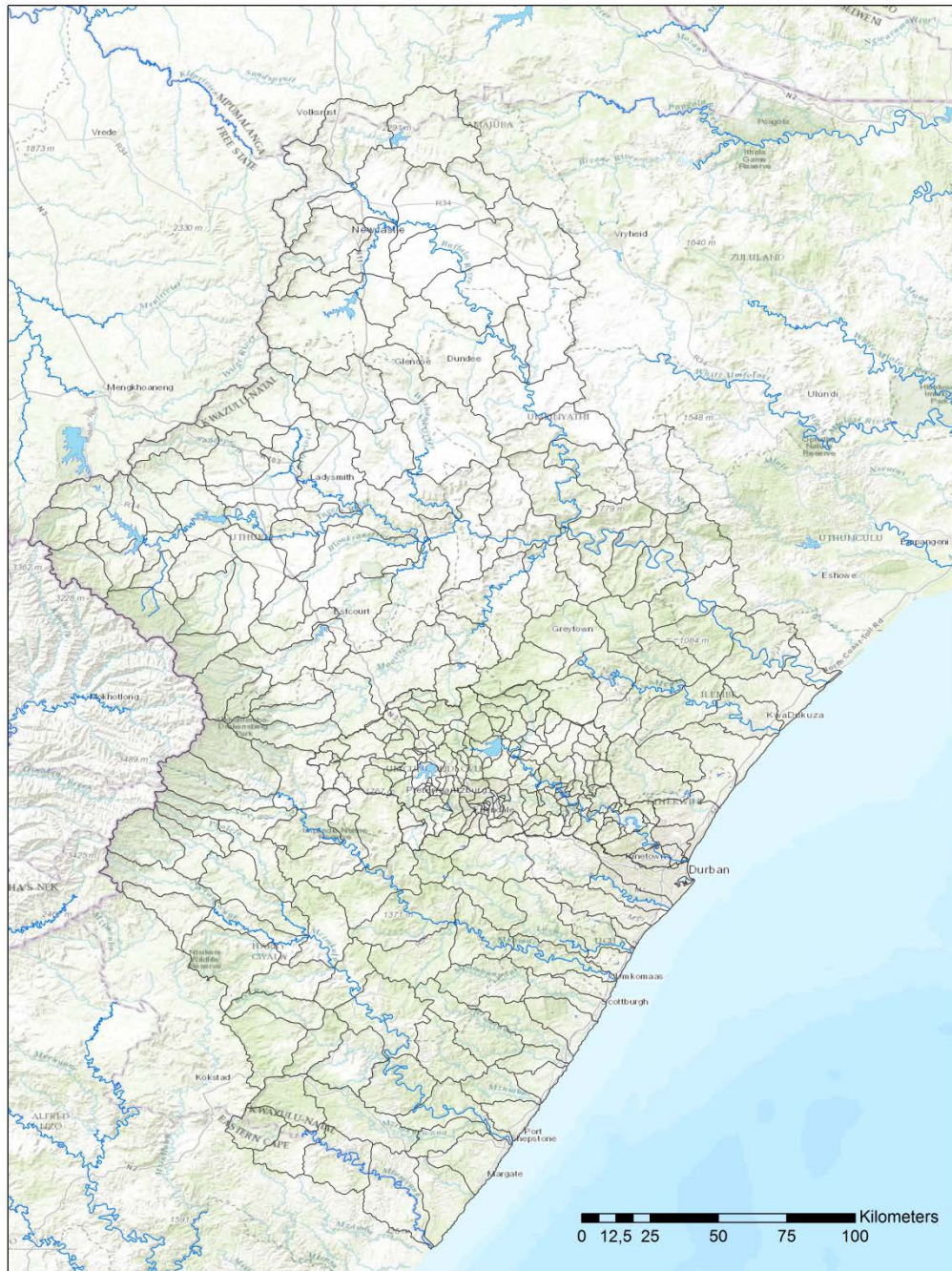


Figure 1. Study area: uMngeni catchment and surrounding basins.

The uMngeni River catchment contains six major upstream dams and has one downstream estuary. The upper parts are characterized by timber production and agriculture (crops, soya and cattle), while the lower parts are more industrialized. At present, the region undergoes rapid urbanization with organically growing cities and it is part of the economically important Durban–Gauteng corridor for logistics and transport.

The three rivers have interbasin transfer schemes that are in place and planned to augment supply in the uMngeni system. The uMngeni River mouth is just to the north of the City of

Durban. Details of these catchments are reported by the various Department of Water and Sanitation (DWS). Umgeni Water (UW) is the principal supplier of water to consumers in the catchment. The study area was expanded to include two Water Management Areas (WMA). WMA 16 (Mvoti to Umzimkul) includes rivers Mvoti, Umgeni, Umkomazi, and Umzimkulu. WMA 13 represents the catchment of Thukela River.

University of KwaZulu-Natal is developing a detail HYPE model for the upper part of uMgeni River catchment and ACRU model for uMgeni River catchment. The SMHI modeling efforts complement those of the partner universities. The SMHI model represents a larger area for direct evaluation of existing and potential future transfers and their impacts on water quantity and quality in uMgeni River as well as in the catchments where the transfers originate.

1.3 Water Management

Twelve impoundments and one weir on three major systems are managed together within Umgeni Water. The Mgeni System utilizes four dams on the uMgeni River and Mooi-Mgeni Transfer Scheme (Table 1). The Mooi-Mgeni Transfer Scheme (MMTS) is being completed in several phases. Phase 1 augmented the capacity by 334 million m³ per year (Umgeni Waters, 2016a). Phase 2A (completed in 2013) added 47 million m³ per year. Phase 2B will add 13 million m³ per year to a total of 394 million m³ per year.

Current demands are slightly greater than the 99% assurance of supply level that will be achieved with completion of Phase 2B (Umgeni Waters, 2016a), indicating additional sources will be needed. The uMkhomazi Water Project is planned to transfer water from uMkhomzi River with a completion date in 2023. Additional alternate sources considered in the planning are wastewater reuse and seawater desalination.

As of December 7, 2016, most dams in the Mgeni system were at 45-65% capacity (Umgeni Water, 2016b). Albert Falls Dam, the largest dam in the system was at 27% capacity due to a lack of water in Midmar Dam and the consequent discontinuation of the transfer from Midmar to Albers Falls during the drought.

Table 1. Dams in Mgeni Water Resource System (after Umgeni Water, 2016a)

Catchment	Impoundment	Gross Capacity million m ³
Mooi	Mearns Weir	5.1
Mooi	Spring Grove Dam	139.4
Mgeni	Midmar Dam	235.4
Mgeni	Albert Falls Dam	290.1
Mgeni	Nagle Dam	24.6
Mgeni	Inanda Dam	251.6
Mlazi	Shongweni Dam [#]	3.8
Msunduzi, Mgeni	Henley Dam [#]	1.5
Total		951.5

Table 2 summarizes raw water quality problems reported in 2010, 2012, and 2016 (Umgeni Water, 2010, 2012, and 2016a). There appears to be a shift toward good and excellent water

quality in the verbal description, although the recent description seems to be focusing more on the intake point rather than the whole impoundment.

Table 2. Water Quality in Mgeni Dams (after Umgeni Water, 2010, 2012, and 2016a)

Catchment	Impoundment	Year	Raw Water Quality Problem
Mooi, Mgeni	Mearns Weir; Midmar Dam	2010	High algal counts associated with high nutrient concentrations, and iron and manganese problems have been experienced on occasion.
		2012	Good water quality in Mgeni inflow. Eutrophication in Mthinzima stream inflow.
	(incl. Spring Grove Dam)	2016	Excellent to good quality from the abstraction point in Midmar Dam. Occasional elevated nutrient concentrations in the inflow rivers to the impoundments as a result of inputs from the catchment. These results in elevated algal counts in the impoundments on a few occasions each year.
Mgeni	Albert Falls Dam	2010	High algal counts associated with high nutrient concentrations and high turbidity/suspended solids.
		2012	Excellent quality in Albert Falls dam, from where water is stored and released for abstraction in Nagle dam.
		2016	Excellent to good quality in Albert Falls Dam at the site from where water is released for abstraction downstream in Nagle Dam. Elevated nutrient concentrations in the inflow rivers to the impoundments as a result of inputs from the catchment, particularly from Howick WWTW and problematic sewer infrastructure in that area.
	Nagle Dam	2010	High algal counts associated with high nutrient concentrations and high turbidity/suspended solids.
		2012	Occasional algal blooms in Nagle dam due to eutrophication in intermediate catchment (feedlots in Nagle dam catchment area).
		2016	Excellent to good quality from the abstraction points in Nagle Dam. Occasional elevated nutrient concentrations and turbidity problems in the inflow to the impoundment as a result of the catchment rain events.
	Inanda Dam	2010	Elevated algal counts, associated with high nutrient concentrations, chemical contamination and high suspended solids.
		2012	Good quality at the abstraction site, which is situated near the Inanda dam wall. Poor quality in upper reaches of the Dam, where there is high algal count from eutrophication and high organic carbon (arising from Msunduzi tributary, which drains Pietermaritzburg, and Darvill WWTW)
		2016	Excellent to good water quality from the abstraction point in Inanda Dam. Poor quality in upper reaches of the Dam due to high algal counts associated with nutrient enrichment from the Msunduzi catchment and Darvill WWTW.

2 Data and Methods

This project adapts an agile approach with incremental model development and responsive scenario analysis (Figure 2). This means that we started with available information and we will improve and refine the results in a step-wise manner, starting with the major inconsistencies and obvious errors and finishing with the minor tuning. Result analysis and model development will thus be performed in an interactive manner throughout the project period. The first round of preliminary results is presented here in this report. Model development is performed in collaboration between hydrological scientists involved from both countries. Future scenarios will be defined in collaboration between hydrologists, social scientists and local stakeholders. The model development and data sources summarized below are described in greater detail in Model Documentation (SMHI, 2016).

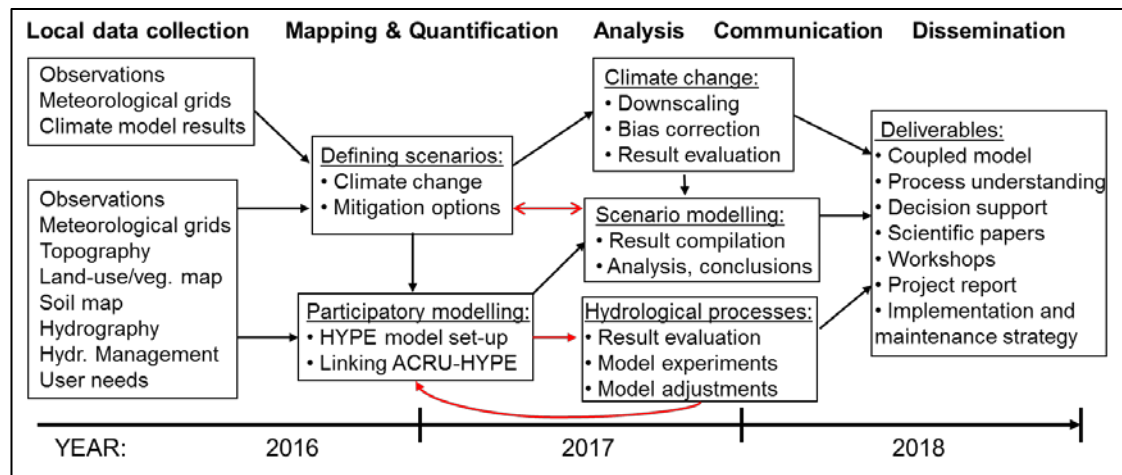


Figure 2. Project outline with tasks and timing over the proposed three years. Red lines indicate the agile interactions between result analysis and model/scenario development.

2.1 Model Development

2.1.1 Data processing

This study uses HYPE model set up with a daily time-step. The study area is divided into 317 sub-basins with area ranging from 0.36 to 830 km². The model results were evaluated for 1988-2013 for flow, inorganic nitrogen (IN), and soluble phosphorus (SP).

Catchment delineation was created by combining existing delineations from three sources: detail delineation of uMngeni River based on DWS quaternary catchments and adjusted by the University of KwaZulu-Natal during their development of the detail HYPE model. Each sub-basin is connected to the downstream basin to form a hydrological network from source to sea.

Land use and soil information were combined to form so called Hydrological Response Units (HRUs), units of land that behave differently in a hydrological perspective given the same meteorological forcing. Each sub-basin would then have a unique distribution of HRUs.

The HYPE model has explicit routines for simulating lakes and regulated dams. Data on areas and depths of the most significant dams were used to be able to simulate these important hydrological features.

The most important water transfer schemes were also included in the model set-up. These include the water transfer from the Mooi River and water abstraction for drinking water from some of the major dams in the area. Data on the magnitude of the transfers is available as time series from the Department of Water and Sanitation and was included in the model as yearly means.

Crop information was included in the model using advice from partners at the University of KwaZulu-Natal. This information included estimates of timing and amount of fertilizer applications.

The contribution of nutrients to the watercourses from population sources (waste water) were estimated from population statistics, per capita coefficients of nutrient excretion and information on the locations and status of sewage treatment plants.

2.1.2 Calibration

Following compilation of all relevant data into a format suitable for HYPE, the model was calibrated to fit observations of flow (see Figure 3 for locations of flow measurement stations) and nutrient concentrations in various locations in the modelled domain. The aim of the calibration was to achieve as good overall performance as possible in the area. Water was calibrated first as a good hydrological model is critical for obtaining a good water quality model. Efforts were made during the calibration process to match the volumes and dynamics of the flow measurements at stream flow gauging stations in the area. This was mainly achieved by adjusting model parameters controlling the evapotranspiration from the various land uses and runoff characteristics of different soil types. Regulation routines for major dams were also introduced.

Calibration of water quality model parameters started after the completion of the water calibration. Again, the levels of riverine nutrient concentrations at the measurements sites in the modelled area were optimized while trying to match the seasonal pattern of the observations.

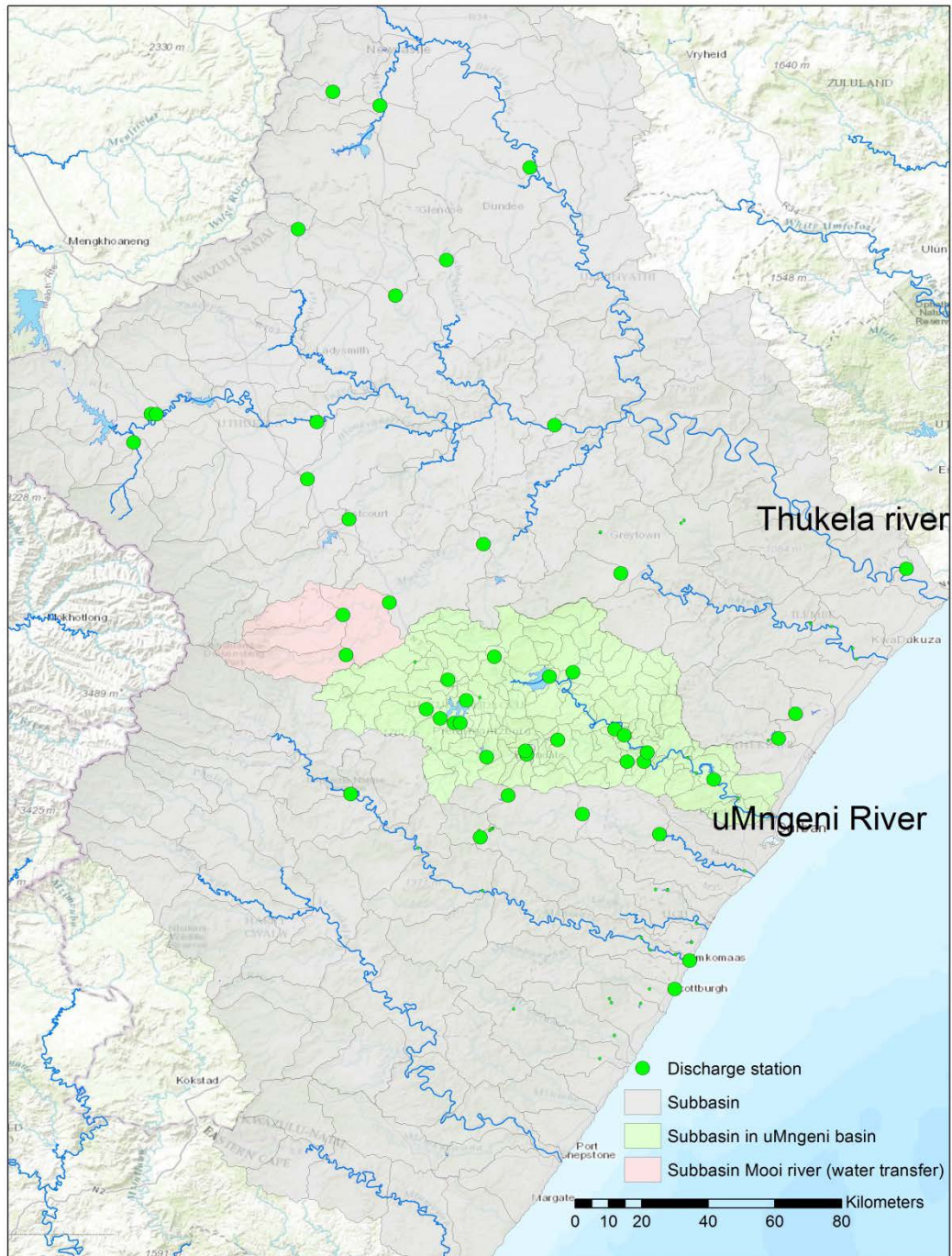


Figure 3. Locations of river discharge stations in the study area.

2.2 Data sources

Data sources were identified together with our collaborators from University of KwaZulu-Natal. Most data sources were national databases providing open data. A summary of input data used in the model set-up is found in Table 3.

Table 3. Summary of data used for the model set-up

<i>Characteristic/ Data type</i>	<i>Original dataset</i>	<i>Data Provider</i>
sub-basins delineation	Quaternary catchments for South Africa, uMngeni catchment delineation	Department of Water and Sanitation (DWS) Umngeni Water (bulk water supplier)
Elevation	HydroSheds	USGS
Soil characteristics	South African Atlas of Climatology and Agrohydrology	The Centre for Water Resources Research (CWRR)
Land use characteristics	National Land Cover 2013-2014	Department of Environmental Affairs
Lakes and reservoirs	Dam register	DWS Dam Safety Office (DSO)
Discharge measurements	Daily time series	Department of Water and Sanitation (DWS)
Daily precipitation and temperature	SMHI Global Forcing Data	SMHI
River nutrient measurements	Nitrogen and phosphorus concentration from river sampling programmes	Department of Water and Sanitation (DWS)
Crops	NLC2000	Agricultural Research Council, Council for Scientific and Industrial Research
Water transfers	Time series of daily flow through pipelines	Department of Water and Sanitation (DWS)

3 Results

3.1 Flow calibration

Much of the initial flow calibration was focused on minimizing error between modelled and observed flow volumes at the flow gauging stations in the modelled area. Of specific importance for good simulation of the water budget in the model is to have accurate precipitation estimates as input and to simulate the evapotranspiration from the different land units well. The spatial patterns of these variables are seen in Figure 4 together with the resulting runoff from land to watercourses. Flow volumes at the gauging stations are relatively generally well captured by the calibrated model (Figure 5), especially in the uMngeni-Mooi river basin. Here, much effort was put on accurately representing the water transfers and abstractions in the model.

The dynamics of the simulated flow is generally in accordance with the observed flow time series at the monitoring stations (Figure 6). Especially the season pattern is well represented by the model, whereas the absolute values of the peak flows and low flows may be improved. This is illustrated in the flow monitoring station furthest downstream in the uMngeni River (Figure 7) where the general dynamics of the flow is well captured but the observed flow peaks are higher than in the model and low flow values are lower in the model.

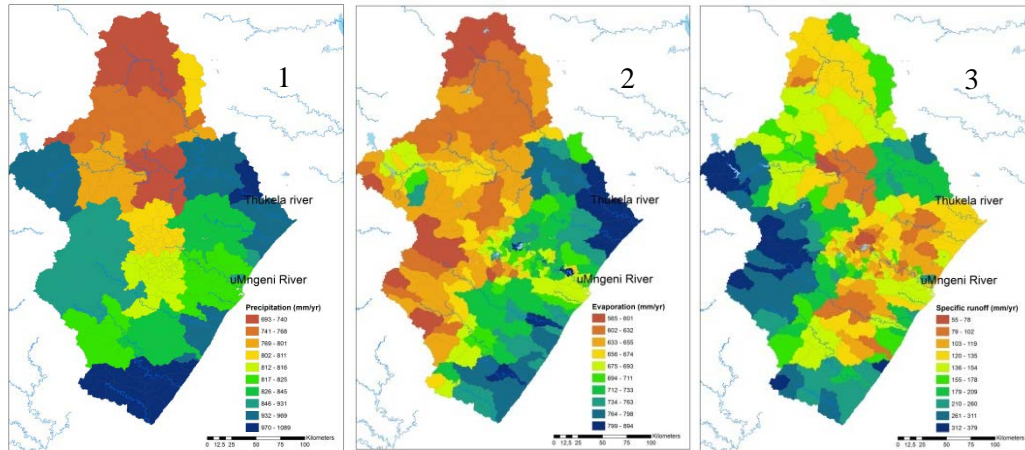


Figure 4. Maps of yearly 1- precipitation, 2- modelled evapotranspiration, and 3- modelled specific runoff in the study area.

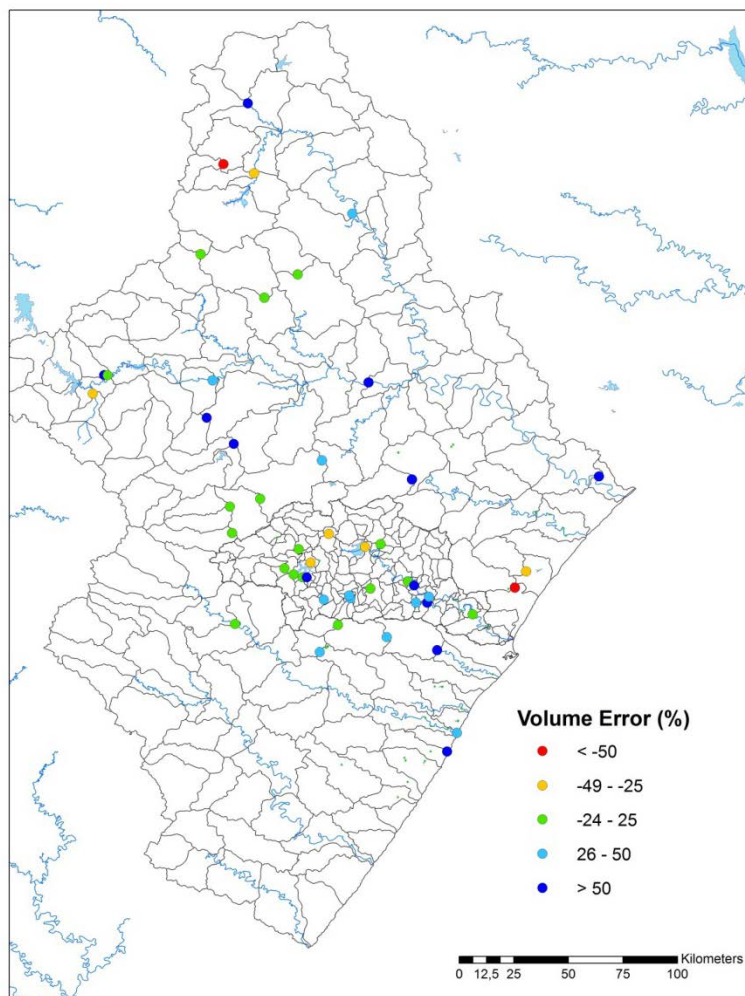


Figure 5. Error in simulated flow compared to observed flow at monitoring stations in the modelled area.

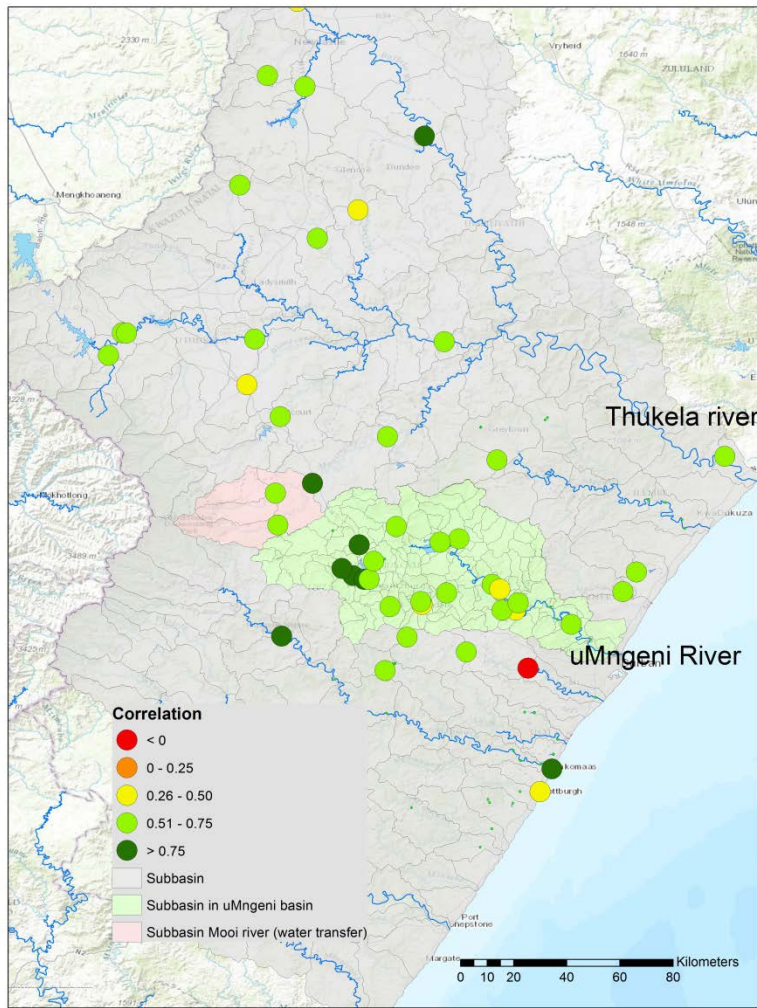


Figure 6. Correlation between simulated and observed flow at the Inanda dam on the uMngeni River

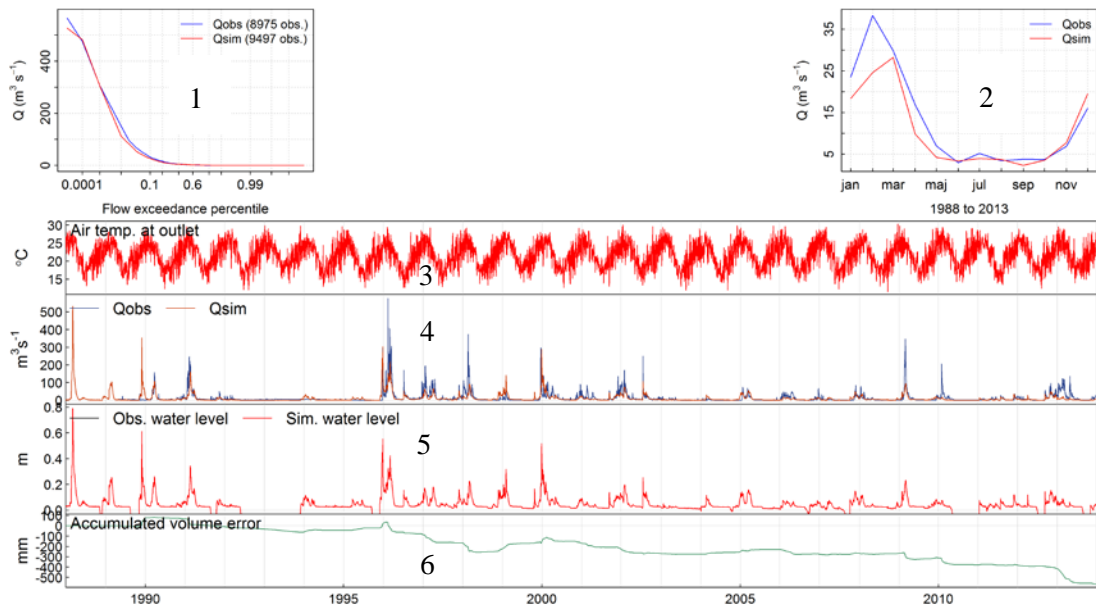


Figure 7. Evaluation of flow simulations at flow gauging station at the Inanda Dam on the uMngeni river. 1- Flow exceedance, 2- Monthly mean, 3- Air temperature, 4- River discharge, 5- Water level in the Inanda dam, 6- Accumulated volume error.

3.2 Water quality calibration

The highest nutrient concentrations are found in the more populated areas of the modelled area, especially around Durban and Pietermaritzburg (Figure 8). Here wastewater of various level of treatment is discharged into the river system contributing to the poor ecological and chemical status of the river water. This is a problem also for more rural areas with lower population density but where the water treatment systems are less developed. The transport of nutrients, which also depend on the flow, increases when moving downstream in the river systems (Figure 9).

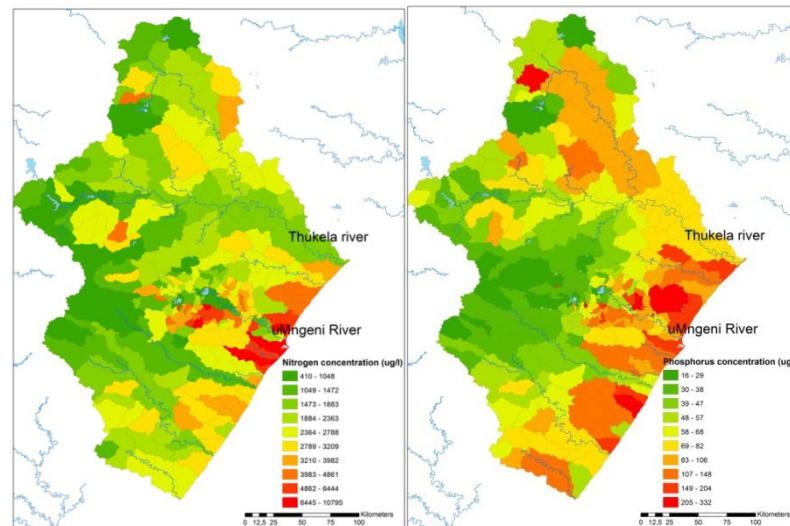


Figure 8. Average simulated concentration of total nitrogen (left) and total phosphorus (right) at the outlet of each sub-basin in the modelled area.

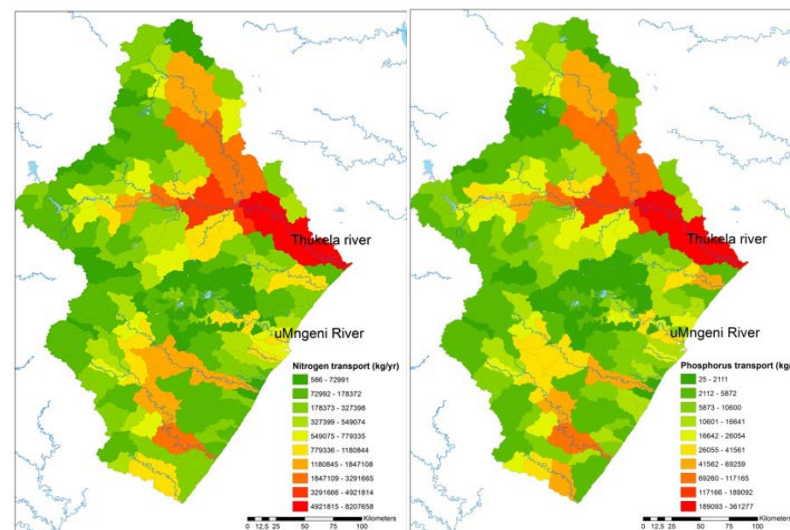


Figure 9. Average simulated annual transport of total nitrogen (left) and total phosphorus (right) at the outlet of each sub-basin in the modelled area.

4 Conclusions/recommendations

This first attempt of modelling the uMngeni River basin and its surroundings with the HYPE model demonstrates the ability of HYPE to be successfully executed in the specific conditions of South Africa.

Many processes in the uMngeni River are largely affected by the large inter-basin water transfers. The transfers increase flows and water levels in reservoirs in one river system while lowering them in another system. Drought continuing from 2014 exacerbates the

impact of excess nutrients. The HYPE model developed for the two WMAs affected by current and possible future water transfers can be used to investigate the impact of withdrawals on water quality in the uMngeni and surrounding basins in a number of model scenarios and to calculate the flow paths of nutrients during dry and wet conditions, respectively. Source apportionment can also be performed to rank sources of nutrients along the river, with respect to e.g. agriculture and human settlements. Such analysis will give some guidance in how operational water-management decisions affect water quality downstream, and which societal sectors that contributes most to eutrophication from source to sea.

At this stage, there are few areas where a model improvement would make it more useful for water managers and allow for detailed scenario analyses. A few key areas were identified for the next stage of the project:

- Better estimates of point sources through acquiring data of waste water discharge from for relevant organizations such as Umngeni Water (bulk water supplier).
- Better knowledge and data of agricultural practices in the basins through cooperation with South African expertise.
- Recalibration of the flow model with special focus on improving modelling of low flow conditions. Comparison with existing ACRU model developed by

The next stage will focus on improving the HYPE model in these critical areas and on developing scenarios of measures to reduce pollution including the potential impact of climate change. Communication with stakeholders is very important during this stage as there are other projects in the region that need to be considered to provide the best and complete information to water managers.

5 References

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