Validation and verification of lawful water use in South Africa: An overview of the process in the KwaZulu-Natal Province.

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Abstract

South Africa is a water-stressed country which has, over the years, strived to adopt a rational, just and equitable way to manage this limited resource. The National Water Act (Act No.36 of 1998) (NWA) provides the legal framework to achieve this objective. Since 2003, the government embarked on a national process to: validate (confirm the quantum of), and; verify (establish the lawfulness of) water uses that exceed domestic requirements. The objective of the project was to determine how much water is allocated for: (1) existing lawful use in accordance with specific requirements of the NWA, and; (2) current water uses. The project identified users with or without registered use entitlements, whether claims for registered uses were correct, under-estimated, over-estimated or false; and confirmed the lawfulness of each water use in accordance with water legislation that pre-dated the NWA. The process included identifying land and non-land based water uses (industrial, mining and bulk potable water supplies, irrigation, crop types and impoundments) using remote sensing (RS) techniques for both a qualifying (defined as two years before the enactment of the NWA) and the current periods. Crop irrigation requirements were estimated using the South African Procedure for estimating irrigation WATer requirements (SAPWAT), while the Gush curves were used to quantify Stream Flow Reduction Activities (SFRAs) due to commercially afforested areas. The boundaries of farm reservoirs were delineated from RS and the volumes calculated using a regression approach. Estimates of the irrigation water requirements, SFRAs and reservoir volumes formed the basis for interaction between the Department of Water and Sanitation and water users to confirm their uses; and subsequently, to update the Water Authorisation and Registration Management System (WARMS), a database of water users. While WARMS indicated a total of approximately 16 000 registered users in the KwaZulu-Natal province, up to 6000 additional water users, mostly currently unregistered,

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are expected to be registered in the updated database. Despite certain project methodology challenges and limitations, the project forms a critical basis for all other aspects of water management, informs macro- and micro-water resource planning, water allocation reform, as well as water use compliance, monitoring and enforcement.

Keywords: Existing Lawful Use, National Water Act, Water allocation, water resources management, water use.

1. Introduction

South Africa is a water-stressed country and has, over the years, strived to adopt a rational, just and equitable way to manage this limited resource. This has been a challenging undertaking not least because of the legacy of the water resource management approaches, through different legislation promulgated at different times during the pre-democracy era. Within the water sector, broad water sector reform process commenced formally in 1995 with the Water Law Review process (DWAF 1995, 1997a). This legal review process culminated in the "White Paper on a National Water Policy for South Africa" (DWAF 1997b) and two sets of water legislation, namely, the Water Services Act (108 of 1997)(Anon 1997) and the National Water Act (36 of 1998)(Anon 1998). The previous water law, which was based on the Roman and Dutch riparian rights principle, gave access to the resource to those who owned land. The minority white population (3 percent) owned approximately 87 percent of the land and a land reform program was established to address this anomaly (Seetal and Quibell, 2003a). Although the riparian rights principle and the concepts of public and private water have been abolished, their legacy still endures and all lawful water use in terms of these and other relevant statutes are recognised by the current National Water Act (NWA) (Seetal and Quibell, 2003b). Water use under the previous legislation was also allowed on the basis of the availability of water and priority of application for its use, i.e. on a first-come-first-served basis. Most of this was largely unregulated, also because of the principle of riparian rights and the concepts of "public" and "private" water and "normal" and "surplus" flows. Regulation of water use was greatest in the Government Water Control areas, i.e. areas where the previous government had developed the resource by building dams, irrigation supply canals and/or providing other infrastructure. Here, co-operative groups of agricultural water users (Irrigation Boards, Water User Associations) had their water use scheduled and an element of self-management prevailed (Seetal and Perkins, 2003). The current emphasis on consumptive use of water by irrigated agriculture is that use by this sector accounts for approximately 62 percent of the water use in South Africa. Although irrigated agriculture makes a relatively small contribution to South Africa's gross domestic product (primary agriculture ~ 4%), it provides socioeconomic stability to rural society (DWAF, 2004). Much of the socioeconomic stability provided by agriculture in rural areas comes from providing employment to the communities. National employment in agriculture is approx. 11 percent, and of this only 10–15 percent is in irrigated agriculture. However, agriculture provides much of the country's food security.

The approach proposed by the National Water Act (NWA) is framework-based and much more strategic, deliberate and dictated by socio-political reforms and socio-economic development needs on a programmatic basis expected for a longer term sustainability and social redress and reformative of the historical status. However, the approach is thus more systematic, but, though necessary for equitable water resource access, resource intensive and demanding in the inception period. Consequently, implementation of the reform aspects of the NWA has been slow (Seetal and Perkins, 2003) leading to increasing unlawful and/or unsustainable use of water resources by both the historically advantaged and disadvantaged sectors of South African society. It is for these reasons that the government of South Africa, through the Department of Water and Sanitation, has embarked on a 'stock taking' program of the use of the water resources of the country by citizens in an effort that may help identify the amount of water that is used, the legality of this use and, hopefully in the process, free some of the resources for reallocation.

The current National Water Act (Act No.36 of 1998) (NWA) thus has the objective of providing the legal framework to achieve the objective of managing the national limited resource. Since 2003, the government embarked on a national process to validate (confirm the quantum of) and, verify (establish the lawfulness of) water uses that exceed basic domestic requirements. The NWA in Section 21 clearly refers "water use" to the consumptive use of water, the use of water to carry waste, storage of water, impeding or diverting the flow in a water course, and stream flow reduction activities (such as commercial forestry) and refers to the use of either the surface or groundwater resource. Thus, this stock taking program, called the validation and verification process, is a significant step in understanding who (i.e. which entity, human or corporate) holds the right to use how much water from what source. This program that would guide water resources (re)allocation reform process and forms the basis for compulsory licensing (a specific intervention in which water allocation plans are developed and licenses for resource use issued on a catchment-wide scale) which has a primary focus on water for irrigation. However, other uses of the water resource are included as well, including the challenges concerning reallocation of licenses for water used to carry waste. Validation is not a word explicitly used in the NWA. However, the continuation of an existing lawful use is very dependent on what was happening in the 2 years prior to the implementation of the relevant section of the NWA. As a result the validation and verification (V&V) process looks at two time periods; the so-called "*qualifying period*" defined as two years before the enactment of the NWA (taken as October 1997 to September 1999 for surface water and October 1996 to September 1998 for groundwater) and the "*current period*".

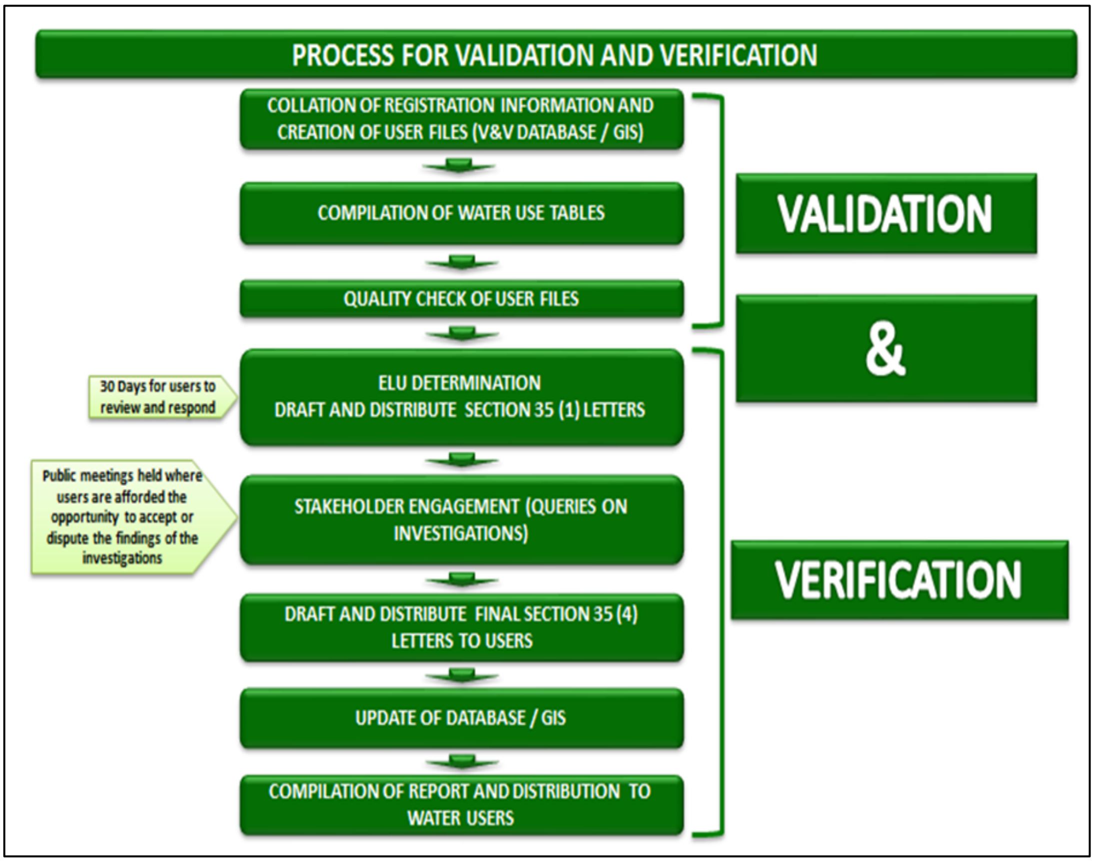

Figure 1. Conceptual framework for the Verification and Validation process in KwaZulu-Natal.

The primary purpose of the V&V exercise, carried throughout the country, is to determine Existing Lawful Use (ELU) of national water resources. Water uses validated in the qualifying period form the preliminary determination of ELU, and those uses validated in the current period for water resource management purposes. Once a final determination of the extent of existing lawful use has been made, any unlawful water use must be stopped.

Anyone wishing to appeal the determination of the extent of existing lawful use may apply to the Water Tribunal. Only once a registered water use has been validated and verified can DWS issue a certificate of Verification outlining the extent of ELU. In this paper we use the KwaZulu-Natal V&V process as a case study and Figure **1** provides a schematic diagram of how the process was executed.

Specific objectives of this paper are to provide detailed information on how the V&V process was conceptualized and executed in the KZN province of South Africa. Secondly we explain the data collection, analytical, and dissemination methods and we give examples of typical results of the water use and irrigation water requirement patterns under different land uses averaged over a period of 66 years (1950-2015). Lastly we provide insights on how we see the V&V process unfolding for the rest of the country culminating in the compulsory licensing phase.

2. Materials and methods

2.1 Study area

KwaZulu-Natal (KZN in short**,** and known as "the garden province") is a province of South Africa located in the southeast of the country, with a long shoreline along the Indian Ocean on its eastern side and shares borders with three other provinces (the Eastern Cape, Mpumalanga and Free State) and countries (Mozambique, Swaziland and Lesotho). The capital of the province is Pietermaritzburg and its largest city is Durban, and is the second most populous province after Gauteng (which houses the administrative capital city, Pretoria, and the commercial capital, Johannesburg) in South Africa.

KZN covers an area of approximately 106,000 km^2, with three distinct geographic areas – the lowland, generally narrow coastal, region along the Indian Ocean, which slightly widens in the northern part of the province, the central Natal Midlands comprising undulating hilly plateau rising toward the west with the western Drakensberg and northern Lebombo Mountains which form a solid basalt wall rising over 3,000 m beside Lesotho border and low parallel ranges of ancient granite running southward from Swaziland, respectively. The coastal regions typically have subtropical thickets and deeper ravines; steep slopes host some Afromontane Forest. The midlands have mostly moist grasslands and isolated pockets of Afromontane Forest. The north has a primarily moist savanna habitat, whilst the Drakensberg region hosts mostly alpine grassland. The area's largest river, the Tugela, flows west to east across the center of the province. The province contains areas of rich biodiversity of a range of flora and fauna. The iSimangaliso Wetland Park and the uKhahlamba Drakensberg Park have been declared UNESCO World Heritage Sites. The iSimangaliso Wetland Park, along with uKhahlamba Drakensberg Park and Ndumo, are wetlands of international importance for migratory species, and are designated as Ramsar sites.

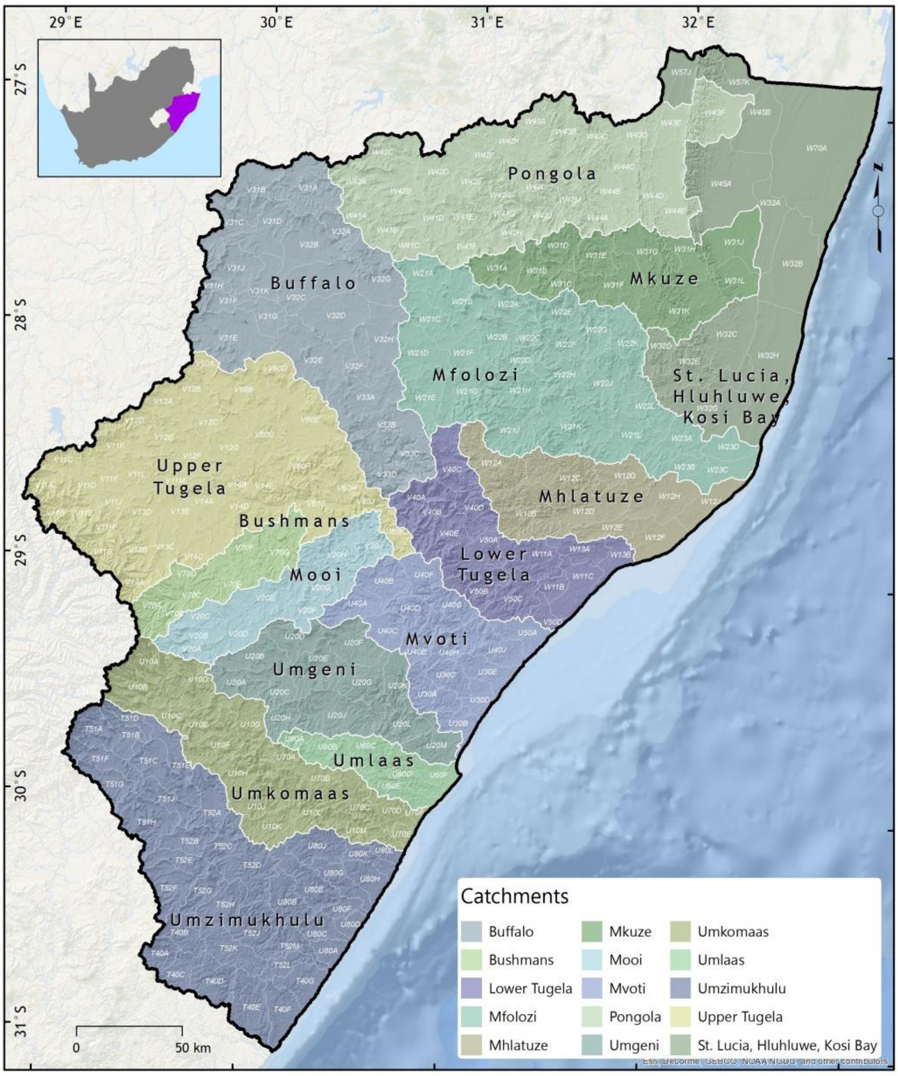

Figure 2. The main catchments in the KwaZulu Natal Province.

The topography of the province has resulted in a varied climate. In general the coastal areas experience a subtropical climate while the inland regions become progressively colder. Durban on the south coast has an annual rainfall of 1009 mm, with temperatures range of 11-28°C and the Drakensberg Mountains can experience heavy winter snow. The Zululand north coast which support extensive sugarcane growing farms around Pongola has the warmest climate and highest humidity. South Africa is divided into nine Water Management Areas

(WMAs), of which the Pongola-uMzimukhulu covers the whole of KwaZulu-Natal province. Further and for management purposes, the country's drainage is divided into primary, secondary, tertiary and quaternary catchments. This division generally refers to some major river systems and their tributaries and the province is made up of about fourteen (14) major river systems or catchments. Figure **2** shows the catchments that make up the hydrology of the province. The current and recorded information of water use within the KwaZulu-Natal Province generally resembles the broader known and expected national picture. Table 1, constructed from the WARMS database (admittedly not very accurate), shows the various aspects (patterns, types, quantities, etc.) of the hydrology and water use in the province.

Table 1. A summary of the hydrology and water use of the KwaZulu-Natal province (Source: WARMS database)

Hydrology	
Number of Quaternary catchments	294
Total area (km^2)	105 300
Average Precipitation (mm)	855
Total Runoff ($Mm^{\mathbf{3}}$)	13 762
Min % Runoff	5.6
Ave % Runoff	16.1
Max %Runoff	40.9
Water Use*	
Domestic & Industrial (Mm^3)	953.89
Agricultural (Mm^3)	1 151.79
Stream Flow Reduction (Mm^3)	590.17
Transfer out water (Mm^3)	568
Totals (Mm^3)	3 263.85
% of runoff used	24

** It is admitted that the addition of water use is adding water of different assurances of supply , but this is to get an approximate % of use.*

2.2 Identification and delineation of crop fields, crop types, forestry and impoundments

To delineate and identify crop areas and types, an image classification approach was used. This involved:

- Acquiring historical and current Landsat satellite images.

Landsat Thematic Mapper (TM) 5 and Operational Land Imager (OLI) 8 satellite images acquired from http://eartheploerer.usgs.gov were used to extract waterbodies or water impoundments, crop and plantation type and areas, for year 1998 and 2015, respectively. The Landsat sensor provides imagery at a ground resolution of 30 m in six multi-spectral bands covering the visible and near-infrared parts of the electromagnetic spectrum. The 1998 images gave information on the qualifying period while the 2015 images represented the current period. Acquired satellite images were pre-processed using Atmosphere Correction for Flat Terrain (ATCOR 2) software. ATCOR corrects for the atmospheric interference of the radiation, and converted digital numbers (DN) to surface reflectance – for easy comparison between past and current images (Richter et al., 2009). All 8 scenes for each period were mosaicked and clipped to the KZN boundary layer (Figure 3).

- *Field data collection to identify major crops across the province.*

  A purposive and road sampling approach was used. Ancillary data was used to understand the occurrence of crop areas – including existing current farm boundaries, google earth and national land cover products (2014 version). Several points were generated on various unknown crop types. Field campaigns were undertaken to identify those unknown types of crops.
- *For current, the collected sampling points (crop types) were used to undertake supervised classification* – to identify different classes such as pasture, maize, vegetables or other crops, pineapples and other annual crops. The first step was to extract crop areas from the image, to constrain the classification process. Classifiers such as maximum likelihood (ML), support vector machine (SVM), artificial neural network (ANN) and spectral angle mapper (SAM) classifiers were explored. The products from the best performing classifiers were used.
- *The classified images for current and existing land use maps were used to train the historical or qualifying period images.* Same classifiers as stated above were also tested for crop identifications.

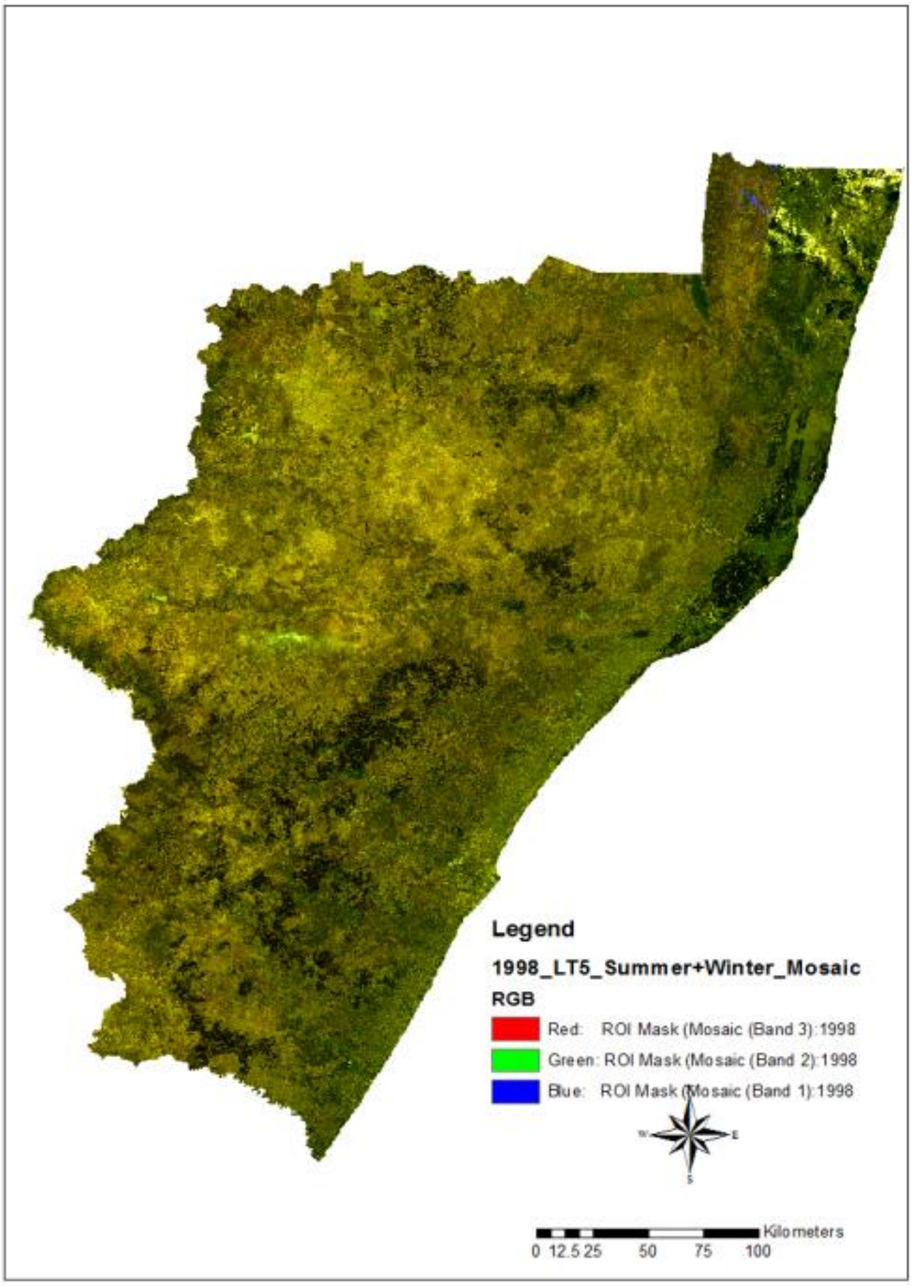

Figure 3. Landsat 5 1998 mosaic of 8 (scenes) images covering the KwaZulu-Natal province (true colour: 123-BGR).

Extraction of waterbodies from remote sensing data can be challenging depending on the state of the water quality, but there is eminent progress. Clear waterbodies are easy to pick up from satellite images using conventional water index such as normalized difference water index (NDWI) (Xu, 2006). Turbid water with high sediments presents a challenge, and are not easily extracted using conventional indices (NDWI). In this study, the normalized difference vegetation index (NDVI) thresholding, i.e. NDVI < 0 was used to extract clear waterbodies. For the turbid waterbodies, thresholding the total brightness (i.e. sum of reflectance in the visible spectral region) was used. These techniques were able to extract waterbodies or dams as small as 900 m^2. In case some dams were missed and not correctly classified, manual editing was done using the advanced editing tool in ArcGIS.

2.3 Establishing the water use, irrigation water requirements and stream flow reduction

After identifying the crop types, forest species, and their spatial extents using remote sensing, the next step was to determine the water use (actual evapotranspiration - ET), irrigation water requirements of the crops and stream flow reduction due to forestry. For perennial crops and commercial forests this information was calculated per annum while seasonal totals were derived for seasonal crops taking into account the cultivar (i.e. early, mid or late season) and the planting dates. Information on the planting dates of various crops was obtained from the WARMS data base. Estimates of ET and irrigation water requirements were obtained using the SAPWAT 3 model (Van Heerden *et al.*, 2008). SAPWAT was developed strictly following the internationally acclaimed FAO 56 (Allen *et al.*, 1998) principles. In this approach, ET is calculated as the product of a crop coefficient (Kc) and evapotranspiration from a short grass reference surface which is healthy, uniformly covering the ground, and is not short of water (ETo). SAPWAT uses the four stage crop coefficient approach wherein different coefficients are derived for the initial, crop development, full cover and maturity phases. In addition, the ET was simulated as the algebraic sum of the transpiration and soil evaporation components via the use of a basal crop coefficient (Kcb) and a soil evaporation coefficient (Ke), respectively (i.e. Kc = Kcb + Ke) according to Allen *et al.* (1998). The gross irrigation requirements were then calculated from the ET and rainfall data taking into account the irrigation transmission losses, and distribution uniformity of different types of irrigation systems as detailed by Van Heerden *et al*. (2008).

To capture the seasonal and year-to-year variability in the atmospheric evaporative demand, and hence the irrigation water requirements across the province, 50 years of daily weather data (1950-1999) derived by Schulze and Maharaj (2006) was used. This data was further extended using daily data from January 2000 to December 2015 thereby extending the simulation record to 66 years. SAPWAT was run for each of the 270 quaternary catchments in KZN using data from a weather station located at the centroid of each catchment. Data from 63 weather stations operated by the South African Sugar Research Institute (SASRI), the Agricultural Research Council (ARC) and the South African Weather Services (SAWS) was used to derive the data for each catchment. Soil type data for each quaternary catchment was derived from the land type data base (AGIS, 2007; Sililo *et al.*, 2001; ARC, 2004) developed by the ARC. Unless otherwise specified by the property owner, we assumed that cereals, pasture, vegetables, and sugarcane were irrigated using the sprinkler drag line system while fruit trees were irrigated using micro-sprinkler irrigation.

Stream Flow Reduction as a result of forestry was derived using the Gush curves (Gush *et al.*, 2002). According to this approach, the impact of forestry on stream flows is calculated as the incremental water use by the forest over and above that used by the indigenous baseline vegetation that grow in the area. The curves were derived using the ACRU model (Schulze 1995) and these distinguish between streamflow reduction under shallow, medium and deep soils for eucalypts, pine and wattle species.

2.4 Estimating the storage capacities of the farm reservoirs

An algorithm was developed to delineate the 1999 and 2015 reservoir boundaries (the so called qualifying and current periods) of farm reservoirs from Landsat imagery. The characteristics of 710 registered dams were sourced from the Dam Safety Office database (DSO, 2016) of the Department of Water and Sanitation (DWS, formerly the Department of Water Affairs). The database excludes many small reservoirs (mostly farm reservoirs) that are exempt from the dam safety permit system. Within geomorphological homogeneous regions relationships between the stored water volume and the reservoir surface area of small reservoirs are consistent (Liebe *et al.*, 2005). Hence, the soil terrain, which describes the terrain or relief of an area quantitatively by means of two parameters; percentage of level land and local relief was used in the study (**Error! Reference source not found.**2; ARC, 2004).

The capacity-area relationships were derived from the assumed full supply surface area and storage capacity of registered dams, grouped according to their surrounding terrain. The established relationships were then used to estimate the storage capacities of farm reservoirs based on the remotely-sensed surface areas.

A series of satellite images with less than 15% cloud cover were used for the study. Landsat Thematic Mapper (TM) 5 were acquired for the qualifying period (1999); while Operational Land Imager (OLI) 8 satellite images were acquired for the current period (2015; USGS, 2013) acquired in January 1997 were used for extracting waterbodies.

Table 2. Terrain parameters used in the South African Land Type Survey (ARC, 2004)

Percentage level land		**Local relief (m)**		**Terrain type description**
Symbol	**Class**	**Symbol**	**Class**	
A	> 80	1	0-30	Level plains
		2	30-90	Level plains with some relief
		3	90-150	Plains with open low hills or ridges
		4	150-300	Plains with open high hills or ridges
		5	300-900	Plains with open low mountains
		6	> 900	Plains with open high mountains
B	50-80	1	0-30	Rolling or irregular plains with low relief
		2	30-90	Rolling or irregular plains with some relief
		3	90-150	Rolling or irregular plains with low hills or ridges
		4	150-300	Rolling or irregular plains with high hills or ridges
		5	300-900	Rolling or irregular plains with low mountains
		6	> 900	Rolling or irregular plains with high mountains
C	20-50	1	0-30	Open low hills or ridges with low relief
		2	30-90	Open low hills or ridges
		3	90-150	Open hills or ridges
		4	150-300	Open high hills or ridges
		5	300-900	Open low mountains
		6	> 900	Open high mountains
D	< 20	2	30-90	Low hills or ridges
		3	90-150	Hills or ridges
		4	150-300	High hills or ridges
		5	300-900	Low mountains
		6	> 900	High mountains

The normalized difference vegetation index (NDVI) thresholding, i.e. NDVI < 0 was used to extract clear waterbodies. For the turbid waterbodies, thresholding the total brightness (i.e. sum of bands in the visible spectral region) was used. These techniques were able to extract waterbodies or reservoirs as small as 900 m^2. Waterbodies that are not reservoirs were eliminated in the ArcGIS 10.3 environment using existing coverages of waterbodies such as wetlands.

3. Results and discussion

3.1 Remote sensing products

Dominant classes mapped included maize, pineapple, pasture, sugarcane, maize and pasture, other annual crops including vegetables. The full range of crops assessed for both the qualifying and current periods is as summarised in Table 3. The spatial distribution of crop types and plantation areas and waterbodies for current and qualifying periods is reported in Figure **4**. The overall accuracy of the current and qualifying crop type and plantation mapping is >80 and =<70%, respectively. The overall accuracy for the qualifying period is less by ~10% from the current period, and is dependent on the quality of the image used, Landsat 5. Finally, all land use products were overlaid to the cadastral data to determine the ownership of these land use in each property.

Table 3. Summary of the major crop types in KwaZulu-Natal.

Cereals	**Pasture**	**Horticultural crops**	**Other**
Maize	Seasonal e.g. rye grass	Avocado	Sugarcane
Wheat	Perennial e.g. kikuyu	Citrus	Chillies
		Macadamia nuts	Soybean
		Cucumber	Beans
		Cabbage	Sunflower
		Spinach	Butternut
		Tomato	Lettice
		Water melon	
		Carrots	
		Potato	
		Broccoli	

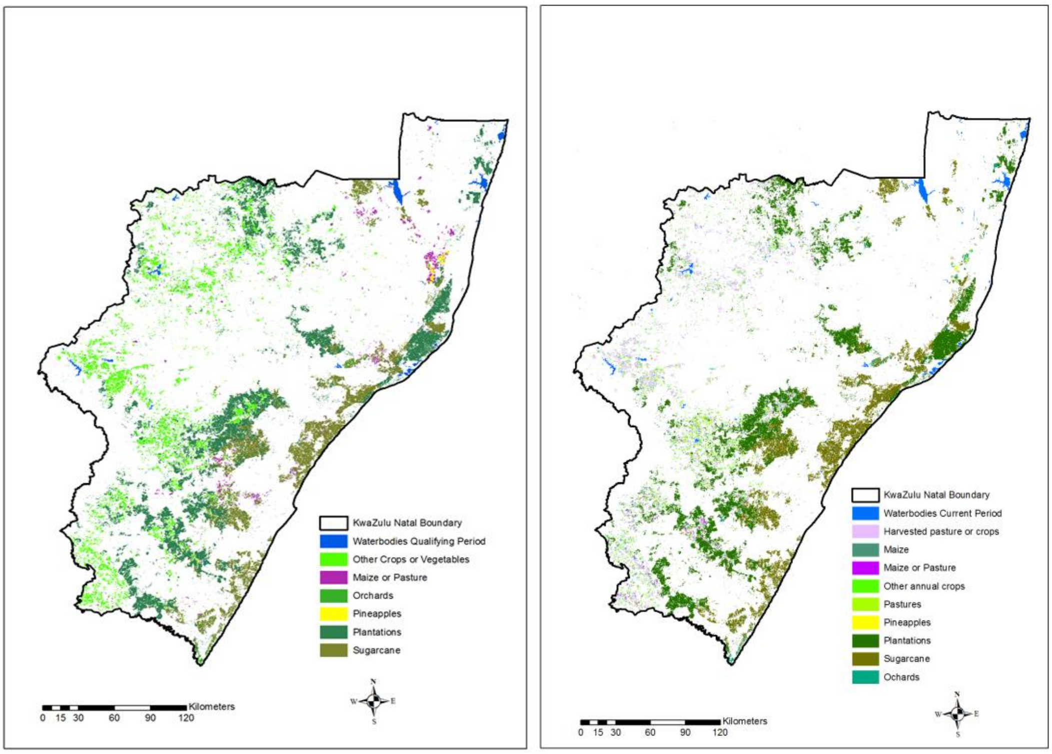

Figure 4. Distribution of some of the crop types, plantations and waterbodies in KwaZulu-Natal for the qualifying (left) and current (right) periods.

3.2 Crop water use and afforestation

Sugarcane is by far the most common crop while pastures and horticultural crops also cover extensive areas. As expected, the water use and hence the irrigation water requirements of the crops varied from place-to-place in the Province and from year-to-year. The range of values of the maximum and minimum irrigation requirement suggest that irrigation is absolutely critical for sustainable crop production in some catchments, mainly those situated in the low rainfall areas further inland. In other catchments however, the irrigation requirements were clearly low especially those situated in high rainfall areas in the coastal regions.

Overall fruit trees and sugarcane had the highest average annual water use rates around 1 200 mm (Table 4) followed by pastures (~ 800 mm) while the other crops used much less water. Sugarcane had the highest average gross irrigation requirement (> 6 400 m^3/ha/y). Small crops such as beans, butternut and watermelons required the least irrigation needing as low as 1 390 m^3/ha/season. Surprisingly, herbs such as chillies and vegetables such as spinach had fairly high irrigation requirements (close to 4 400 m^3/ha), likely because they are produced all year round. Summer crops tended to use more water than those grown in winter. Stream flow reduction activities ranged from around 380 m^3/ha/y for young pine forests to as much as 1 600 m^3/ha/y for fully grown eucalypts on deep soils.

Table 4. Summary of the water use (ET) and gross irrigation requirements for selected crops in the KZN Province.

Crop type	ET (mm)			Irrigation (mm)		
	Max	Avg	Min	Max	Avg	Min
Avocado[1]	1543	1205	141	1360	631	54
Beans	575	439	326	400	215	30
Butternut	640	312	233	420	139	40
Cabbage	485	388	220	480	211	80
Carrots	534	375	283	520	330	120
Chillies[1]	1508	583	321	1020	438	60
Citrus[1]	1476	1093	100	1020	529	100
Cucumber	961	529	399	500	272	80
Maize	816	668	360	960	302	22
Perennial pasture[1]	1263	783	101	1040	337	60
Seasonal pasture[1]	1175	723	454	920	598	180
Pine apples[1]	699	605	345	560	297	160
Potato	599	449	356	500	292	20
Soybean	843	539	360	700	262	60
Spinach	996	763	65	880	474	160
Sugarcane[1]	1468	1150	126	1160	643	80
Sunflower	1141	434	350	560	181	40
Tomatoes	960	579	220	860	312	60
Watermelon	780	393	291	460	167	40
Wheat	758	526	25	720	479	40

[1] – denotes annual values

3.3 Farm reservoir storages

The standard root square of all the capacity-area relationships established oscillates between 90% and 73% (Figure **5**).

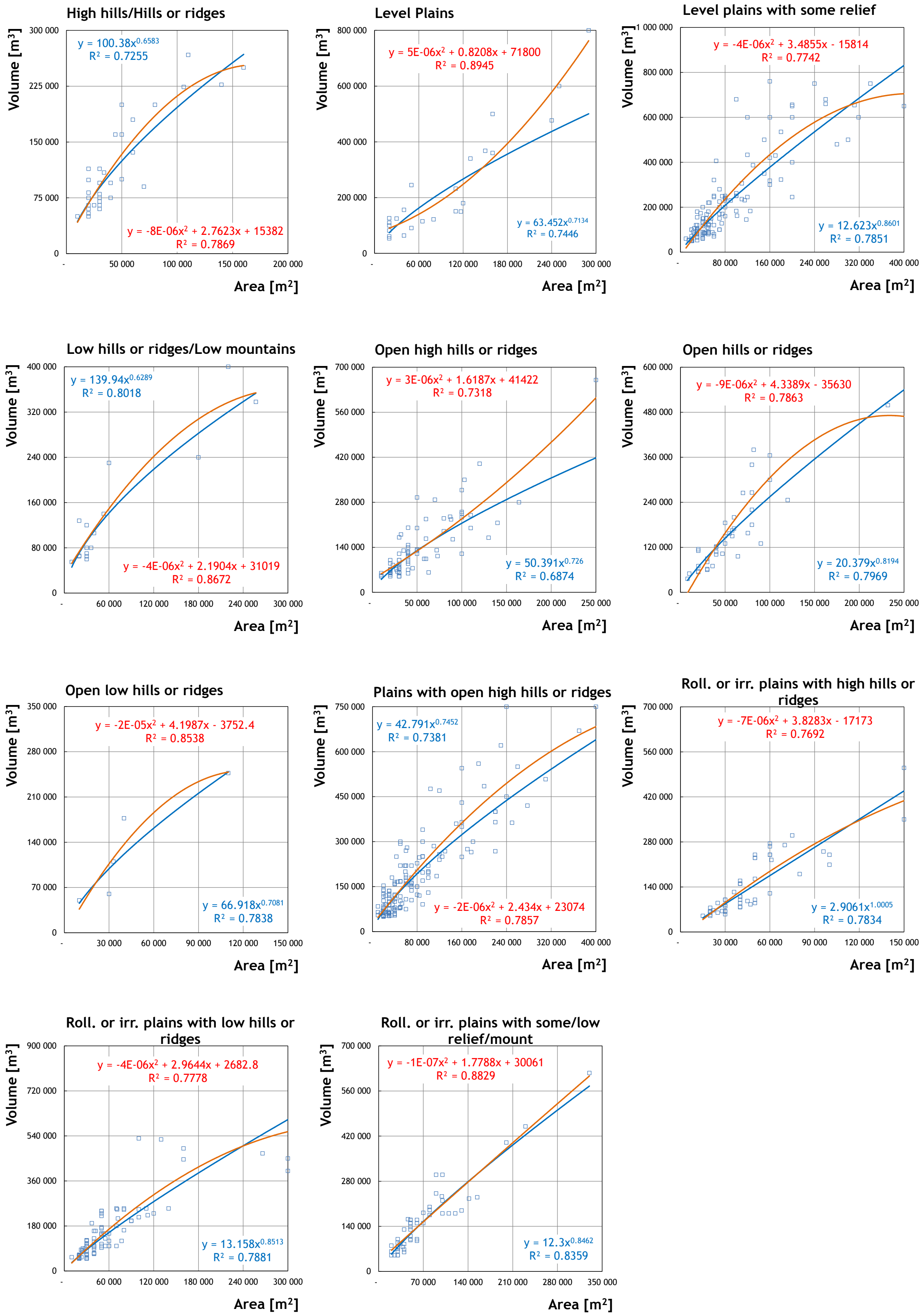

Figure 5. Capacity-area relationships established for the various reliefs of the KwaZulu-Natal Province.

Results indicate that during the qualifying period (1999), the KwaZulu-Natal province had about 2 911 reservoirs with a combined volume of 4 521 Mm^3. The number of reservoirs in 2015 reached 6 656 with a total volume of 6 330 Mm^3. Most of those additional ones are farm reservoirs that have a combined volume of 1 808 Mm^3.

4. Process and data uncertainties

The accuracy of remote sensing products is dependent on the quality of satellite data and its characteristics, e.g. Landsat's spatial and radiometric resolution as well as the date for image acquisition. Small waterbodies less than 900 m^2 are automatically missed with this type of data. The radiometric resolution of Landsat 8 is higher (32 bit) than that of Landsat 5 (8 bit), and could have influenced the accuracy of the qualifying period classification. The other factor that might have influenced the accuracy is the time or date of image acquisition. For KZN, it is difficult to get a cloud free scene in summer, and most of the images were acquired in winter. Winter images can clearly show the irrigated areas with minimal confusion with indigenous vegetation, but sometimes most of the farms are harvested and bare.

The major source of uncertainty in the water use simulations with SAPWAT resides with the estimates of the crop coefficients. SAPWAT uses the four stage crop factor approach wherein separate factors are assigned for the initial, crop growth, maturity and senescence growth stages. These coefficients vary with local microclimatic conditions, soil type, planting density, crop health and nutritional status, irrigation system etc. It is difficult to precisely capture all these variations in practice leading to substantial errors in the water use estimates. Use of crop coefficients based on actual measured data would substantially improve the water use simulations. But reliable data is either sparse or simply unavailable for most crop and forestry species.

The results on the estimation of reservoir capacities need further validation with a subset of reservoirs in KwaZulu-Natal for which surface areas, shapes and depths will be determined with ground-based survey measurements. There are also uncertainties related to the estimation process that may have affected results. For instance, it is not known whether the remotely-sensed reservoir surface areas relate to full supply level. In that case it is possible that capacities would have been underestimated. Such uncertainties and the impact that will have on water resources use and allocation require further research.

5. Conclusions and recommendations

The goal of this study was to assist in estimating the levels and legality of water use, especially agricultural irrigation, in the KwaZulu –Natal province for the qualifying and current periods. To date 14 991 properties have been validated and registered for the entire province. This figure includes some of 6 000 unregistered users identified during this process. From a technical perspective, the qualifying period was a huge challenge given that it was quite difficult to go back in time to establish not only reasonable quantities of water used but also the type of crops that were being grown back then as crop types, and therefore, patterns of water use would be expected to have changed. The use of remote sensing techniques made this possible, though the identification of the crop types remains a challenge given the quality of images available at that time.

The advantage of using Landsat images is the ease of comparison between historical and current images. This enabled the transfer of knowledge from current in terms of training the classifiers to historical period. It could be difficult to achieve the latter when using multi-sensor approaches, at different spatial resolution. For dams and other known classes such as plantations and sugarcane, manual digitizing should be done using satellite images such SPOT 6 and 7, at a spatial resolution less than 2 m. Overall, this study generated useful information both for the Validation and Verification exercise and also for scientific research into the water requirements of crops grown in the province.

6. Acknowledgements

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