Spatial and temporal analysis of the nitrate concentrations in groundwater for South Africa

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A SPATIAL AND TEMPORAL ANALYSIS OF THE NITRATE CONCENTRATIONS IN GROUNDWATER FOR SOUTH AFRICA

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ABSTRACT

The aims of this investigation was to create an updated view of the nitrate distribution for the country, to identify whether there are any gaps or significant changes in the distribution of nitrate concentration over the sampling record and identify areas where nitrate pollution occurs as an ecological hazard for priority research and remediation.

Data was sourced from the national groundwater database for the entire country for the period up until 2008. Previous maps used data pre-1990 and up to 2001. Additional nitrate data was sourced to supplement the NGDB data. The data was evaluated using excel pivot tables, and maps plotted using ArcMAP. Maps of the total count representing the total number of points sampled and their densities for South Africa, as well as the minimum, maximum and average nitrate concentration for the various decades were used to evaluate the extent and duration of nitrate pollution in South Africa. The nitrate concentrations were overlayed on the geological or hydroterrains and land cover for South Africa to investigate if there are links between lithology, land cover and nitrate concentrations.

Comparison of maps compiled for different periods indicate that the Western Cape now has elevated nitrate levels, possibly associated with agricultural stock farming. The Northern Cape Province, in particular the Kalahari has elevated nitrate levels, but a distinct lack of recent sampling may mask the extent of the current spatial distribution of nitrate concentrations. The scarcity of sampling points within urban centres makes it difficult for pollution monitoring and control to take place.

INTRODUCTION

Nitrate concentrations in South and Southern Africa have been studied for decades (Tredoux and Talma, 2006, Tredoux et al., 2004). A nitrate distribution map was produced and published during 2001. The extent to which nitrate occurs and the levels were known as far as the data obtained allowed (Tredoux et al., 2001).

The aims of the investigation were to:

1. Have an updated view of the nitrate distribution for the country;
2. Identify whether there are any gaps or significant changes in the distribution of nitrate concentration over the last two decades;
3. Evaluate which areas are of high priority based on their nitrate levels and possible population numbers and dependence on groundwater as a source of drinking water; and
4. Identify areas for priority research and nitrate remediation.

As is customary in South Africa all nitrate and nitrite concentrations in this paper are expresses as an equivalent quantity of nitrogen (N) except where explicitly stated otherwise.

DATA FORMATS AND PROCESSING

NO_3 and NO_2 as N data were requested from DWAF for all the boreholes in the country until 2008. The data were received in comma separated files (CSV) for each province. Empty values were deleted and the entries were collated into one excel spreadsheet.

The data were summarised in Microsoft Excel using a Pivot Table. Average, Maximum and Minimum values were obtained for each sampling point for all existing data. The data were then plotted using ArcMAP to show the distribution and various concentrations of Nitrogen in South Africa.

RESULTS AND DISCUSSION

Plots of the count, minimum, average and maximum levels of nitrate were compiled for the entire country. Categories selected were based on the guideline values for drinking water nitrate levels.

Table 1: South African guideline values for potable use and livestock watering

Drinking water class	**as N**	**as NO_3**	**Comments**
Nitrate plus Nitrite (mg/L)			DWAF (1998)
Ideal	<6	<26	Negligible health effects
Acceptable	6-10	26-44	Insignificant risk
Marginal	10-20	44-89	Slight chronic risk to some babies
Poor	20-40	89-177	Possible chronic risk to some babies
Unacceptable	>40	>177	Increasing acute health risk to babies
Livestock watering	**as N**	**as NO_3**	DWAF (1996)
Nitrate(mg/L)	0-90.3	0-400	
Livestock watering	**as N**	**as NO_2**	DWAF (1996)
Nitrite (mg/L)	0-12.3	0-40	

The distribution of sampling points is shown in Figure 1 with the data for all data until 2008. What is most notable is the lack of sampling in the Free State and the Northern Cape during this period, in particular the Kalahari which is known to have high nitrate content from the previous version of this map. From the distribution of the sampling points it is evident that groundwater sampling was concentrated in certain areas, e.g. Limpopo Province, Northwest Province, the northeastern part of Northern Cape Province, northern Natal, parts of the Eastern Cape, and large parts of the Western Cape, especially the west coast. The total number of sampling stations were 48 469 individual sampling sites. The minimum sample analysed was one, and the maximum 384, SampleID 165054 at Venterspos goldmine indicating an intensive sampling exercise from 1985 to 1990 during which the 384 samples were taken and analysed. No records after 1990 for this borehole exists in the database.

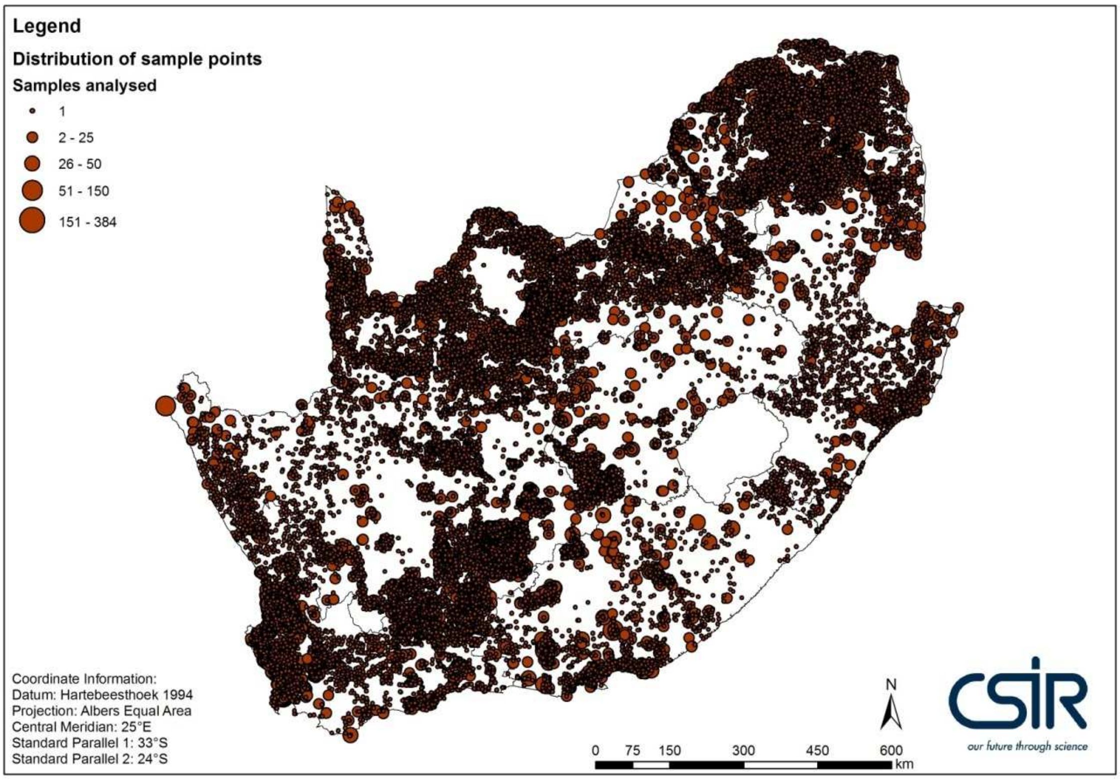

Figure 1: The count of sampling events of NO_3+NO_2 as N per data point from 1990-2008

Figure 2 shows the average concentration of nitrate for all data points until 2008 and Figures 3 and 4 respectively show the average and maximum concentrations of nitrate for all points with concentrations exceeding 10 mg/L as N until 2008. Inspection shows that in areas where the density of points are lower slight differences in the distribution are evident. However, the overall picture provided by these maps are not very different. This implies that the overall pattern of nitrate concentration distribution in groundwater is generally relatively stable.

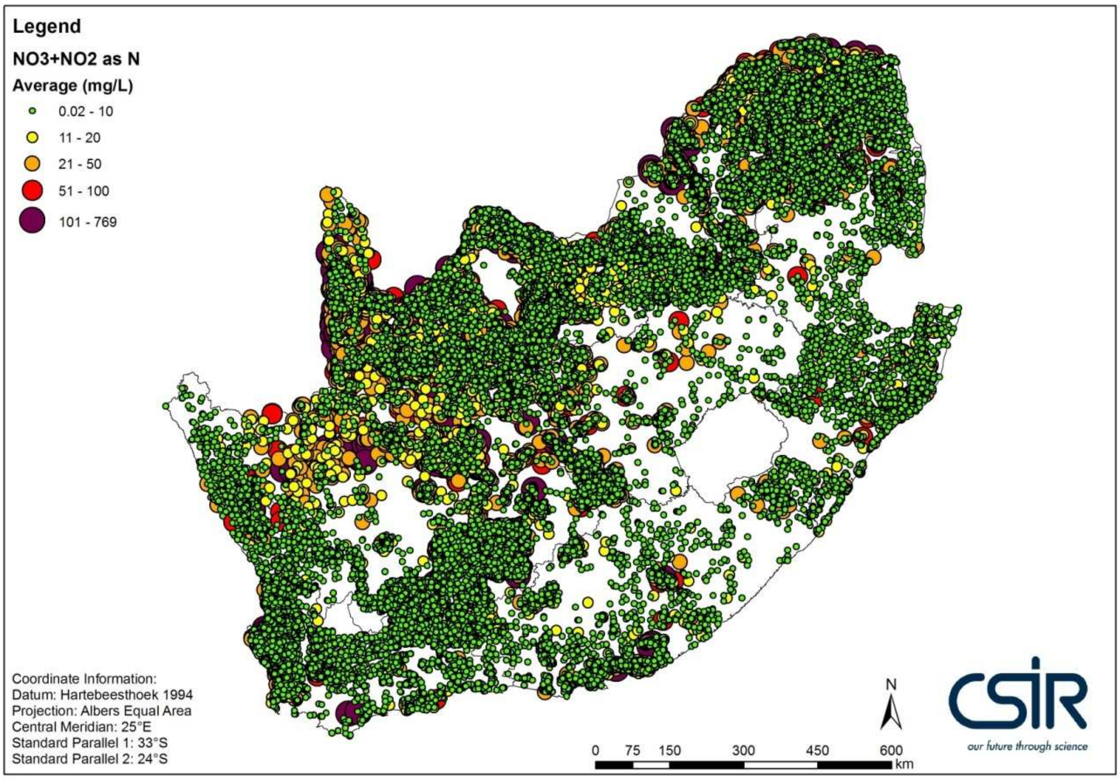

Figure 2: Average NO_3+NO_2 as N for all sampling stations until 2008

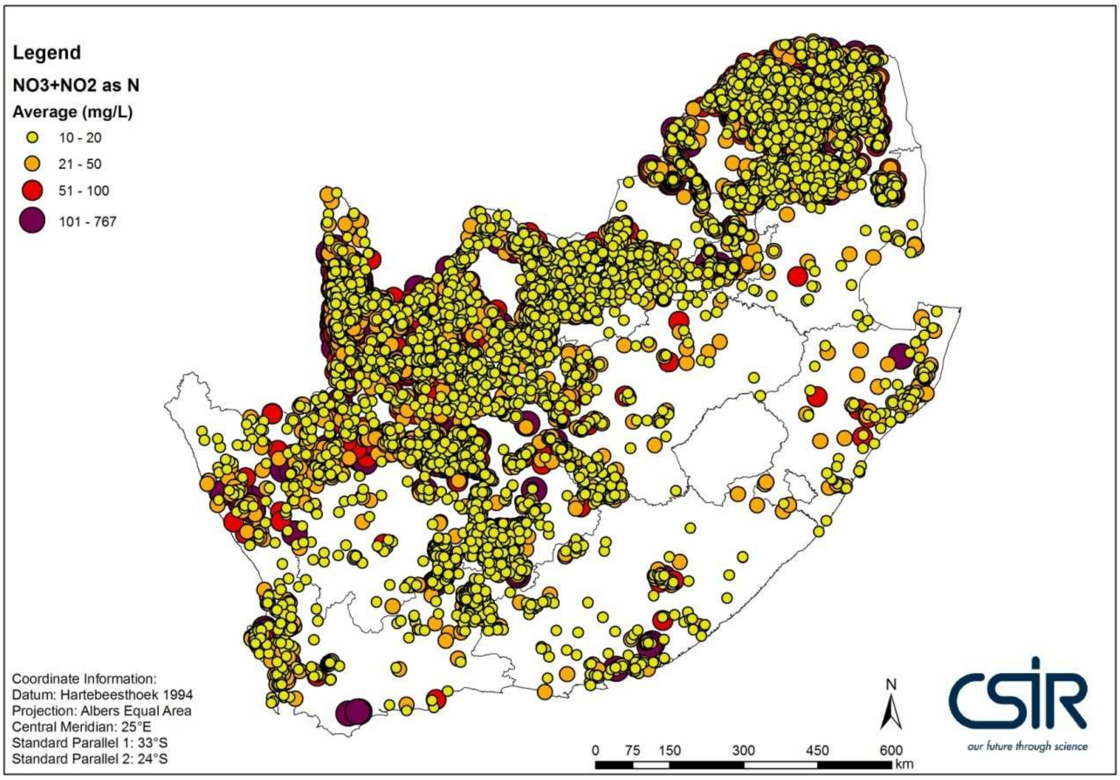

Figure 3: Average NO_3+NO_2 as N greater than 10 mg/L per sampling station until 2008

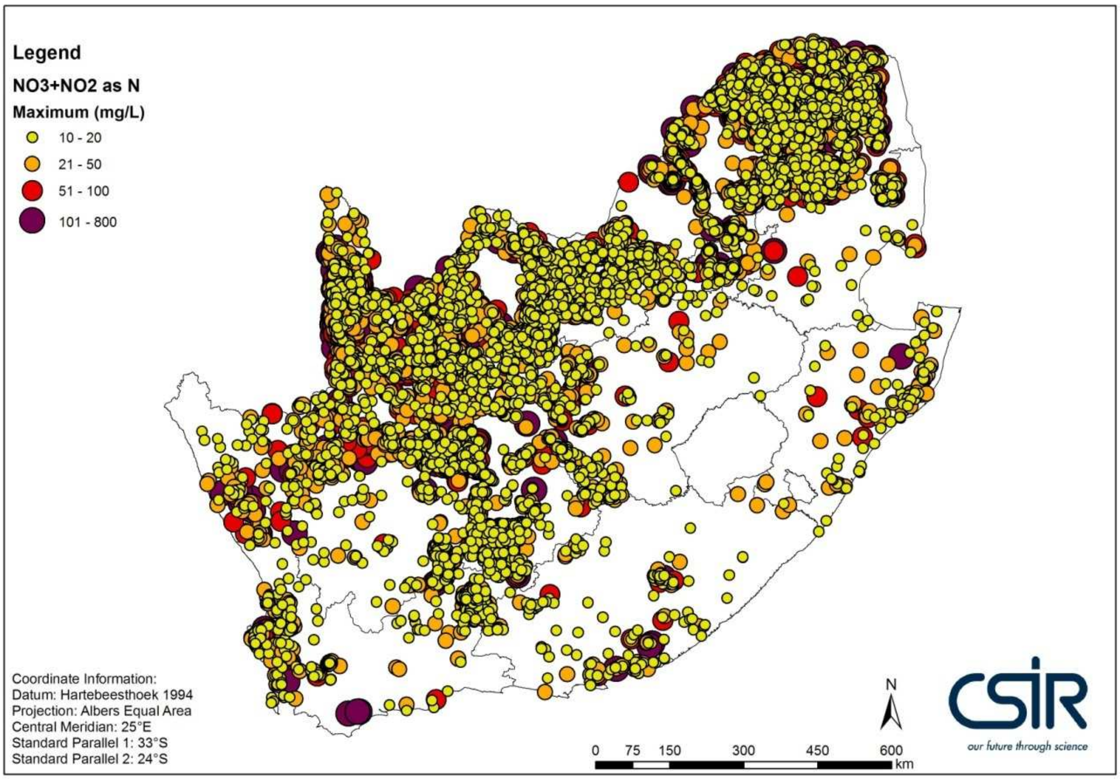

Figure 4: Maximum concentrations greater than 10 mg/L of NO_3+NO_2 as N, per sampling station until 2008

Figure 5 shows the hydroterrains of South Africa. This is a simplified map deduced from the geology of South Africa and known aquifer units (Colvin et al., 2003). This map was used to evaluate which hydroterrains contain elevated nitrate concentrations. Only nitrate concentrations greater than 50 mg/L as N are shown in order not to clutter the map. These levels are well in excess of the guidelines for potable water (Table 1). Figure 5 highlights the area in South Africa where such totally unacceptable levels of nitrate concentrations occur and the hydroterrains they occur in. Areas in the northern part of the country e.g. Limpopo Province, North West Province, and Northern Cape Province, as well as the Western Cape have groundwater concentrations exceeding this level. Very few points with high nitrate occur along the east coast possibly due to the effect of the higher rainfall. The data is summarised in Table 2 per hydroterrain. The average nitrate and nitrite concentrations for the extrusive terrains are significantly higher in comparison to the other lithologies. Conversely, the Karoo Dykes and Sills, Fractured metasedimentary and Carbonate terrains tend towards lower nitrate values. It was concluded previously that geological formations are not generally the source of nitrate and that it was rather physical and other characteristics of the overburden and the bedrock that allow enrichment of nitrate in the groundwater where a pollution source is available (Tredoux, 1993). The so-called “black cotton soil” derived from basalt is prolific in binding nitrogen and the generation of nitrate as demonstrated in the Springbok Flats and elsewhere.

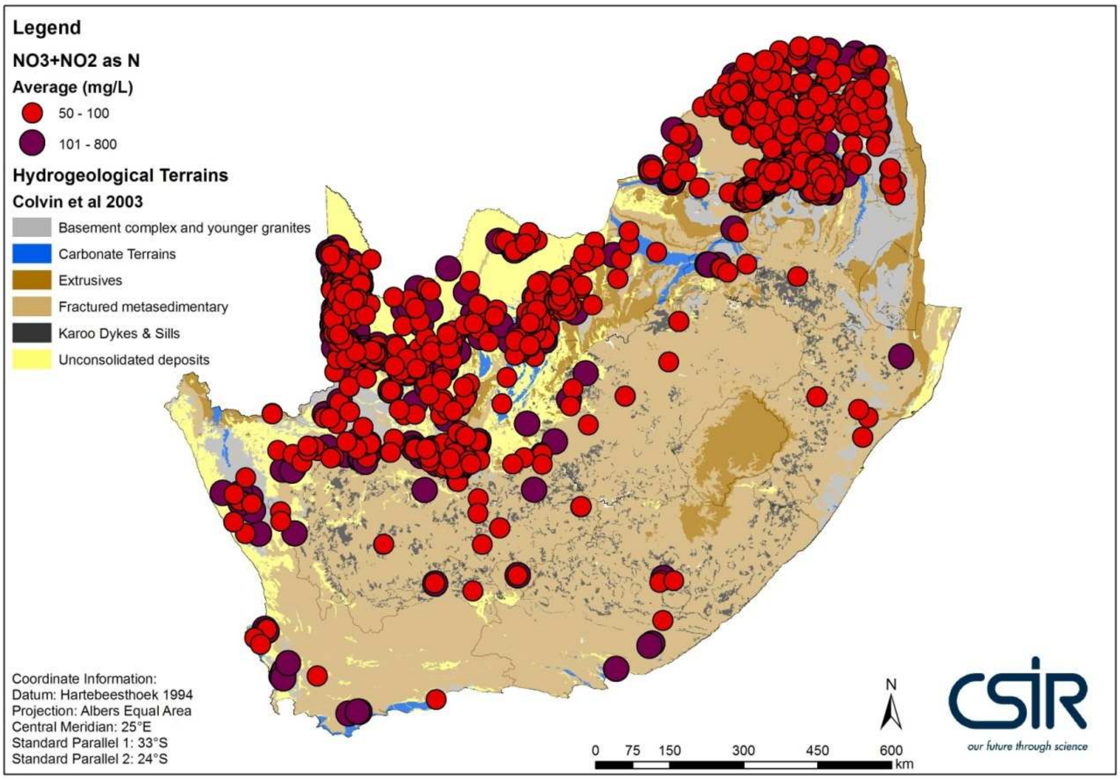

Figure 5: Average NO_3+NO_2 as N greater than 50 mg/L per Hydroterrain

Table 2: Summary of the Average NO_2 and NO_3 as N per Hydroterrain for all available nitrate data

Hydroterrain	Average NO_3 NO_2 as N	Average of Max NO_2+NO_3 as N	Average of Min NO_2+NO_3 as N
Basement complex and younger granites	12.6	13.3	12.1
Carbonate Terrains	7.4	7.9	7.1
Extrusives	18.9	20.4	17.7
Fractured metasedimentary	5.9	6.5	5.6
Karoo Dykes & Sills	6.8	7.1	6.6
Unclassified	3.6	4.3	3.3
Unconsolidated deposits	13.1	13.7	12.8
Grand Total	10.2	10.8	9.7

Figure 6 shows the average NO_3 and NO_2 as N per class greater than 50 mg/L for the National Landcover 2000 and summarised in Table 3. Elevated levels of nitrate can be seen in the Mines and Quarries landcover class with an average in excess of 40. The table shows that the Urban areas have elevated levels of nitrate, in particular the rural cluster, formal township and informal township. Indigenous forests and forest plantations have low nitrate concentrations in groundwater.

Woodland has a higher nitrate while degraded forest and woodland have even higher nitrate levels. One can also see elevated levels of nitrate within the agricultural sector, namely, permanent and temporary commercial dryland, and temporary subsistence dryland farming. Although it would seem obvious that the elevated nitrate has to be related to the application of fertilizer to land Conrad et al., (1999) found that the nitrate had the isotopic character of soil nitrogen and not of fertilizer. Thus it was concluded that the tilling of the soil caused nitrification of the soil nitrogen and leaching of nitrate into the subsurface.

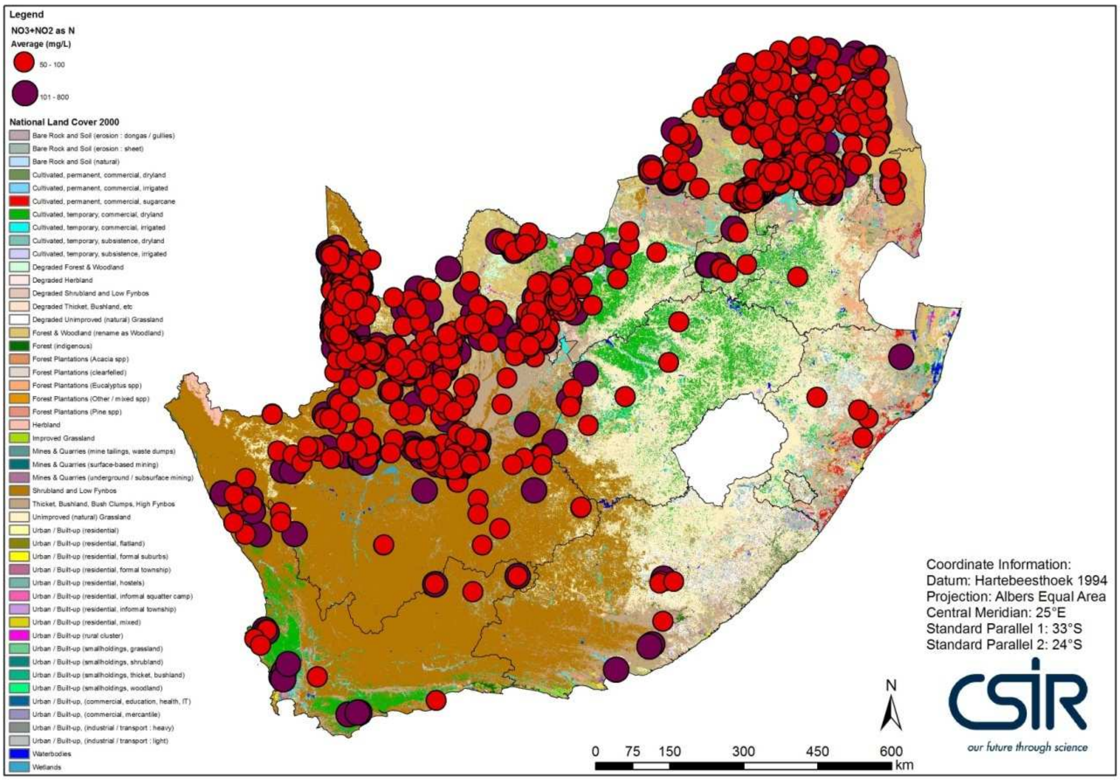

Figure 6: Average NO_3+NO_2 as N greater than 50 mg/L per National Landcover 2000 class

Table 3: Average nitrate and nitrite values per National Landcover 2000 class

NLC2000 Landcover Classes	Average NO3+NO 2 as N	NLC2000 Landcover Classes	Average NO3+NO 2 as N
Bare Rock and Soil (erosion : dongas / gullies)	4.1	Mines & Quarries (underground / subsurface mining)	40.8
Bare Rock and Soil (erosion : sheet)	8.8	Shrubland and Low Fynbos	8.7
Bare Rock and Soil (natural)	3.2	Thicket, Bushland, Bush Clumps, High Fynbos	9.9
Cultivated, permanent, commercial, dryland	15.3	Unimproved (natural) Grassland	6.6
Cultivated, permanent, commercial, irrigated	3.9	Urban / Built-up (residential)	7.9
Cultivated, permanent, commercial, sugarcane	3.9	Urban / Built-up (residential, formal suburbs)	5.1
Cultivated, temporary, commercial, dryland	14.4	Urban / Built-up (residential, formal township)	18.5
Cultivated, temporary, commercial, irrigated	6.8	Urban / Built-up (residential, hostels)	0.0
Cultivated, temporary, subsistence, dryland	12.3	Urban / Built-up (residential, informal squatter camp)	6.8
Cultivated, temporary, subsistence, irrigated	3.4	Urban / Built-up (residential, informal township)	13.0
Degraded Forest & Woodland	16.2	Urban / Built-up (residential, mixed)	3.3
Degraded Shrubland and Low Fynbos	6.2	Urban / Built-up (rural cluster)	18.9
Degraded Thicket, Bushland, etc	9.6	Urban / Built-up (smallholdings, grassland)	2.9

Degraded Unimproved (natural) Grassland	4.2	Urban / Built-up (smallholdings, shrubland)	8.0
Forest (indigenous)	2.4	Urban / Built-up (smallholdings, thicket, bushland)	8.8
Forest Plantations (Acacia spp)	0.4	Urban / Built-up (smallholdings, woodland)	9.6
Forest Plantations (clearfelled)	2.1	Urban / Built-up, (commercial, education, health, IT)	7.2
Forest Plantations (Eucalyptus spp)	3.1	Urban / Built-up, (commercial, mercantile)	5.8
Forest Plantations (Other / mixed spp)	0.6	Urban / Built-up, (industrial / transport : heavy)	5.4
Forest Plantations (Pine spp)	1.3	Urban / Built-up, (industrial / transport : light)	2.4
Herbland	2.9	Waterbodies	9.4
Improved Grassland	4.5	Wetlands	12.6
Mines & Quarries (mine tailings, waste dumps)	3.9	Woodland (previously termed Forest and Woodland)	10.9
Mines & Quarries (surface-based mining)	8.7		

Figure 7 shows the results of the interpolation using an inverse distance weighted method. The resultant map is very similar to that produced by Tredoux et al., 2001, however, areas of Northern Cape are now lacking data and areas in the Western Cape are now showing more elevated concentrations.

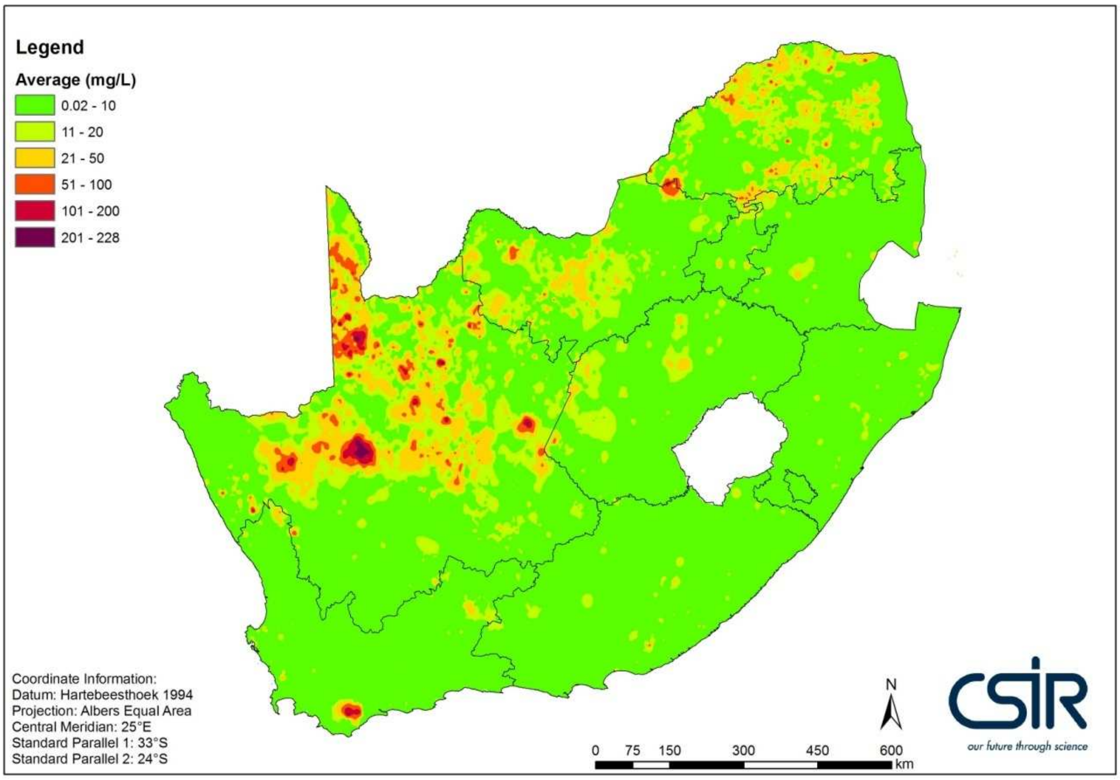

Figure 7: Interpolated N values using the Inverse Distance Weighted Method

Those points with very high levels of nitrate were then plotted on the interpolated map, and figure 8 shows the result. Here only nitrate concentrations above 50 mg/L are shown.

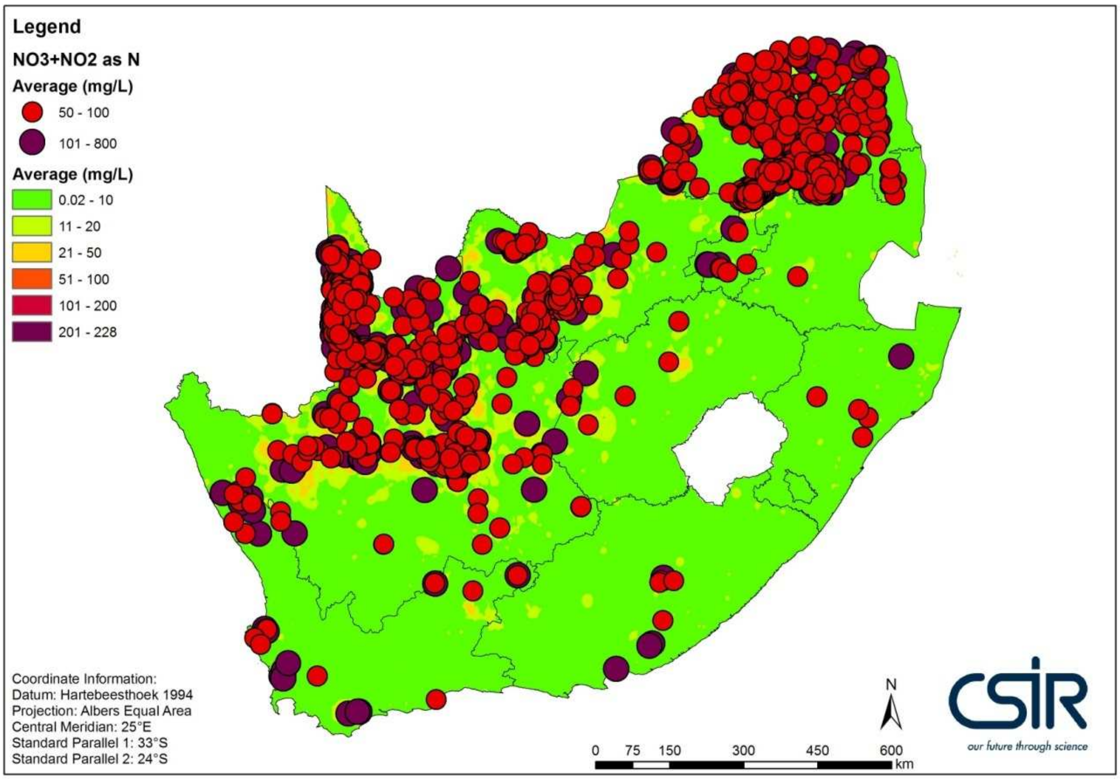

Figure 8: Sampling points with a Maximum NO_3+NO_2 as N greater than 50 mg/L overlain on the Interpolated N map

A CLOSER LOOK

The regions with highly elevated concentrations are shown in more detail in this section. The central part of the country e.g. Free State and some parts of Western and Northern Cape are not covered very well by this dataset. This does not mean that there are no nitrate occurrences in these areas; it simply means that these areas are not sampled or monitored intensively. The reasons for not monitoring certain areas may be numerous and variable e.g. areas with no or small populations, areas with extensive farming or mining areas, etc.

Figure 9 shows all points currently being monitored in the Limpopo Province. It shows elevated concentrations and low concentrations for the same points or points in close proximity. There are also areas where data is lacking. It is known that parts of the Limpopo Province suffers from water scarcity, and if remediation technologies are tested and implemented in this area, then more water may become available for potable purposes in such areas. If pathogenic bacteria are present in the water disinfection may be needed to augment the remediation schemes.

Figure 10 shows the nitrate concentration distribution in the Northern Cape Province. It was noted during data processing and comparison with previous maps that the Northern Cape area is now lacking an extensive amount of elevated nitrate data. The data may be pre- 1990 thus not included in this diagram; however, one would then have to question the reasons for no longer sampling or monitoring points that may previously have shown elevated nitrate concentrations.

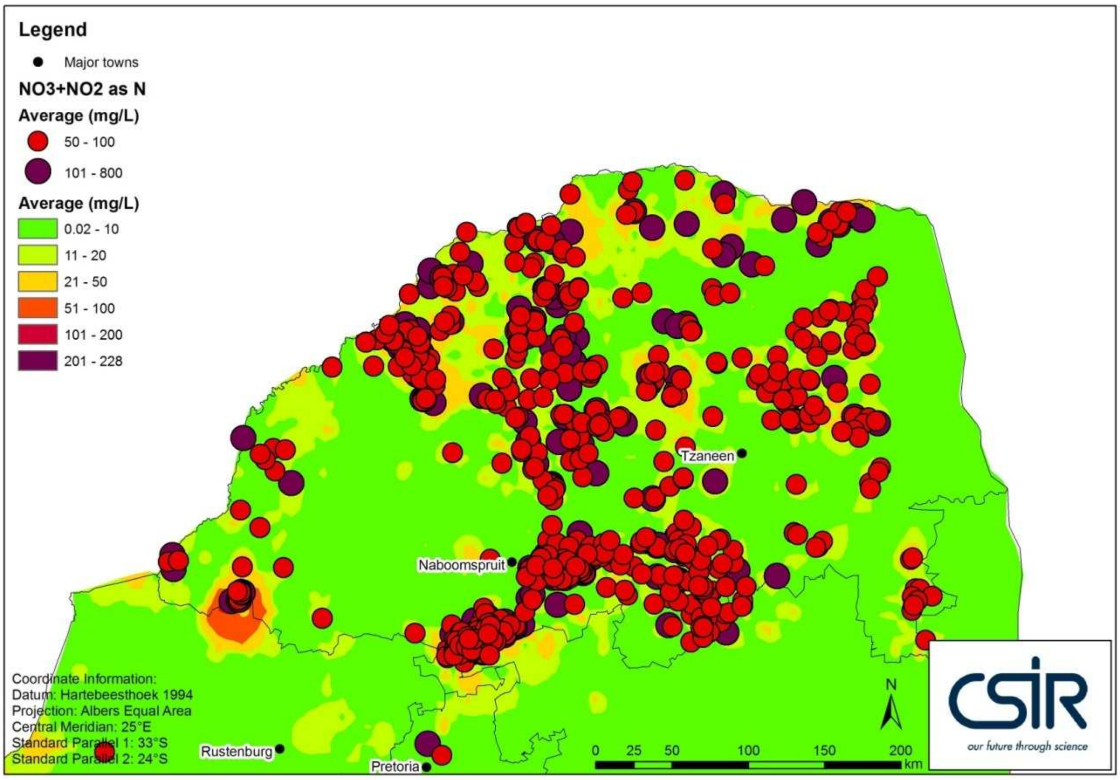

Figure 9: Interpolation and all nitrate concentrations greater than 50 mg/L for the Limpopo Province.

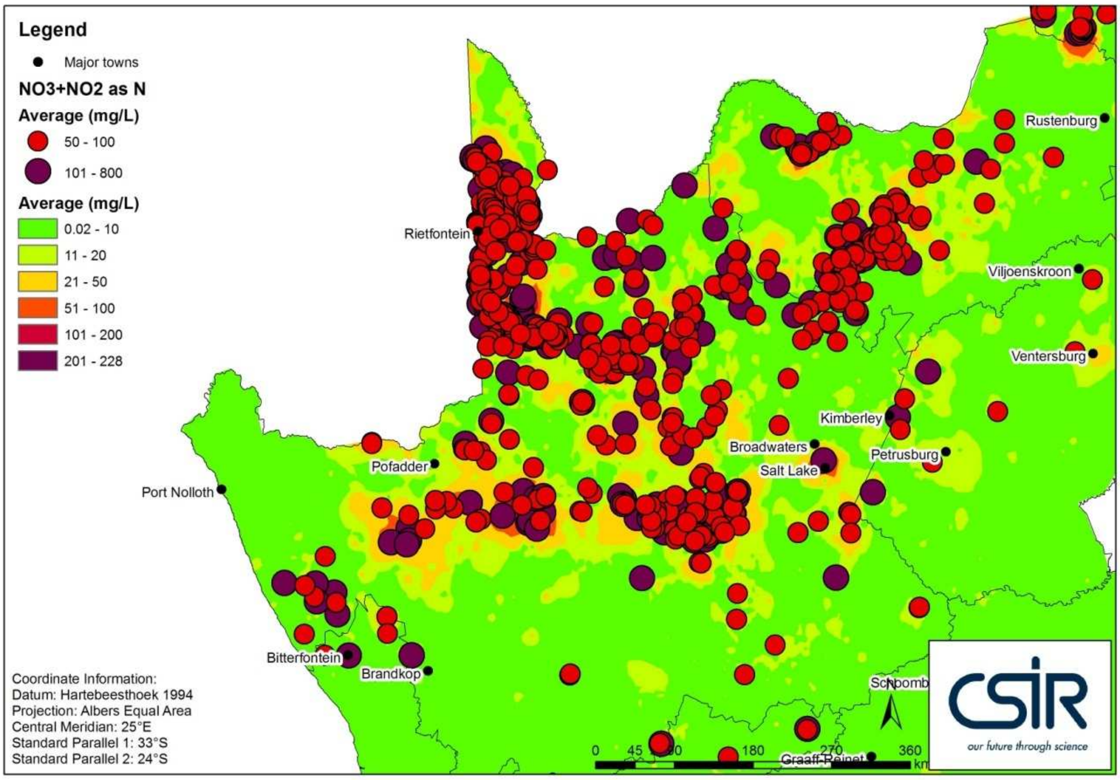

Figure 10: Interpolation and nitrate levels greater than 50 mg/L for the Northern Cape.

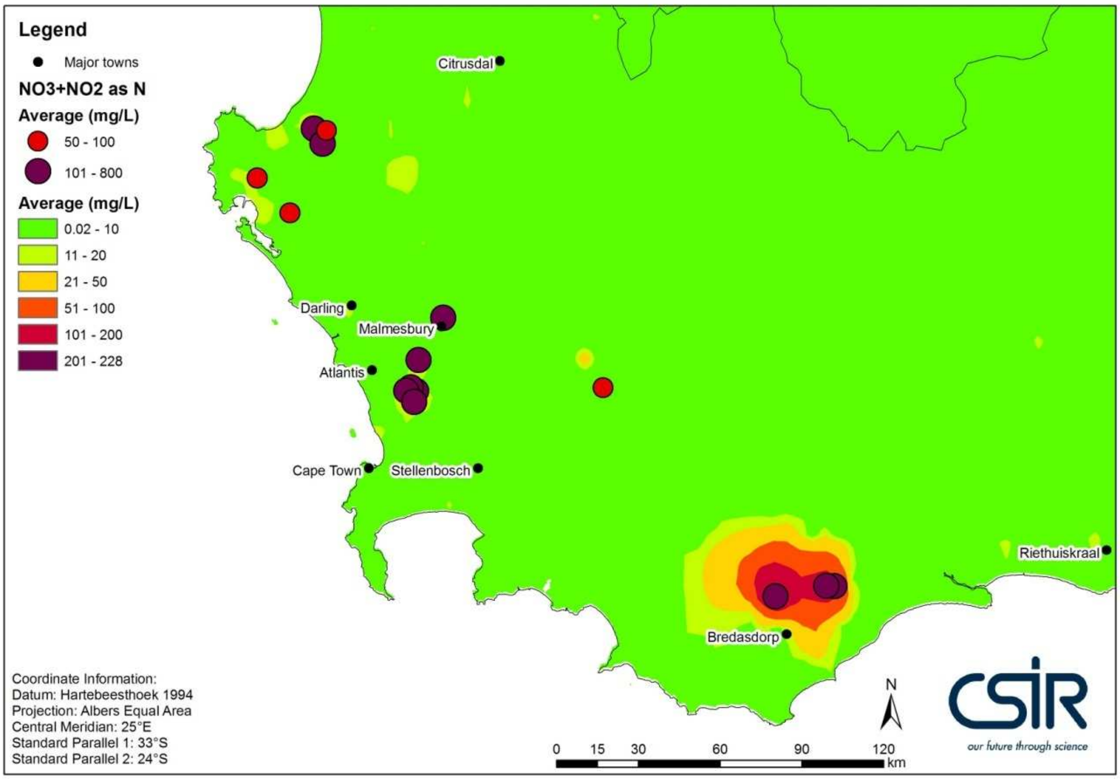

Figure 11: Nitrate distribution in groundwater for the Western Cape Province

The nitrate distribution within the Western Cape Province shown in Figure 11 was disconcerting. Previous maps showed some elevated nitrate levels, but the new data set has values > 100mg/L as N. These seem to plot close to Bredasdorp on the south east coast, and along the western coastal area close to the N7 freeway. Inspection of the data showed that some of these points represent newly drilled boreholes that may not have been included in previous maps.

Conclusions

This exercise proved to be invaluable to the project. Specific areas can now be selected for further investigation. Conclusions drawn from the updated nitrate distribution maps include the following:

- The Western Cape Province would seem to be more affected by elevated nitrate concentrations over the last decade than before,
- The Limpopo Province and Kalahari are still strongly affected by elevated nitrate concentrations.
- There is a scarcity of data points in certain urban centres as well as in the central part of the country.
- Scarcity of data points may affect the interpolation process.
- A part of the Northern Cape Province now lacks data which was used in the previous 2001 map. This may indicate abandonment of well field, a halt to sampling or an error in the database. This area previously had elevated nitrate levels.

Elevated nitrate levels are associated with mining areas, urban areas, in particular the rural cluster, formal township and informal townships. Elevated levels of nitrate within the agricultural sector, namely, permanent and temporary commercial dryland, and temporary subsistence dryland farming. Nitrate pollution and elevated nitrated concentrations in South Africa still persists. The extent and distribution would seem to be increasing with new areas being affected. The lack of data in certain parts of the country may be obscuring the actual extent of the state of nitrate pollution in South Africa.

Although actual site selection should only be done following site visits and evaluation for suitability to the remediation technology criteria, regions selected as areas for priority research and implementation for remediation technologies include: Western Cape (west and south east coastal areas), Northern Cape and Limpopo.

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