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Predicting Aquifer Sustainability of the Modder River Catchment Using CARS Model

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Abstract

This paper presents the concepts of CARS methods and the results of its applications for modelling groundwater sustainability of the Modder River Catchments of South Africa. CARS is derived from the combination of important hydrological parameters that impact sustainable use of groundwater resources and it stand for C- climate, A- aquifer sustainability, R- right to resources and S- socio economics including land use practises. The Modder River Catchment is a Tertiary Catchment of the Orange River System which originates from highlands of Lesotho and flows to the Atlantic Oceans through Namibia. In arid and semi-arid areas of South Africa, farmers and communities only have a limited number of water provision points. This has put more pressure on groundwater and increased the number of wells and boreholes being drilled to access groundwater, which is needed for multiple purposes, especially for agriculture and drinking water. The limited resources of water provision have put undue pressure on aquifers such as the aquifers in the C52 Modder River catchment. The net effect has been depletion and prolonged periods of drought. This has created a need for groundwater sustainability methods, models, and indices such as CARS to predict sustainability of aquifers. The CARS concept is based on the interactions of the factors and physical processes governing hydrological cycles with human induced factors in relation to groundwater sustainability. These interactions (climate-land use-groundwater, land use-surface-groundwater, climate-groundwater) connects the CARS parameters interchangeably. The parameters include rainfall, slope, land use/cover, evapotranspiration, climatic zones, water quality, aquifer yields, rock types, aquifer systems, recharge, population, uses, the permit / licence system and groundwater rights. The parameters were ranked and scored in an index format. The ratings considered the assignment of values to the overall elements in factors: factor (C) climate, factor (A) aquifer sustainability, factor (R) rights/equity verse resources and factor (S) socio economics. Score were assigned with the lowest scores of 1 corresponding to poor practices and the highest score of 5 to good practices. Climate (C) and aquifer sustainability (A) factors were assigned total scores of 30 each, while right (R) and socioeconomics (S) have a scoring of 20 each respectively. The CARS sustainability index scores ranged from 19 for the least sustainable aquifer and 100 for a sustainable aquifer 100. The developed CARS sustainability index was applied to 52 boreholes in the Modder River Catchments of South Africa. ArcView GIS was employed in modelling the response of each of the 52 boreholes to CARS aquifer sustainability concepts. Results shows that 9 boreholes are classified as moderate sustainability which means they are on average sustainable while 43 boreholes are of low sustainability index which suggest they are not sustainable. The new methodology of CARS concepts of modelling aquifer sustainability as applied in this paper to the groundwater of the Modder River Catchment will assist in the sustainable management of aquifers.

Keywords: Aquifer, CARS, groundwater sustainability, land use, Modder River Catchment

1. Introduction

The concept of aquifer sustainability is complex. This is because of the contributory impact of many human activities on groundwater resources. This has increased the need for greater understanding of ground water management [1]. According to World Commission for Environmental Development [2], the concept of groundwater sustainability is frequently discussed. Most debates are on the negative effects of human activity. 'Groundwater sustainability' is defined by the development and use of the resource to address all development needs and changes[3]. Groundwater sustainability shows an optimal state that is not constant or static. Studies have shown that ground water is time and space dependent [4]. It, therefore, needs to be studied so that its change in quantity over time and space is understood. Adequate attempts to quantify of groundwater or its state in terms of sustainability are not yet made despite its wide discussion in the scientific, academic and water management arena. Part of the reason is that sustainability is a complex concept [5] and is not purely scientific [6].

1.1 Sustainability standard for CARS

Systems dynamics [7] is method of analysis for complex systems that are interdisciplinary of which sustainability is one of such systems. System dynamics grounding is in dynamics of non-linear theory and controlled feedback developed in physics, mathematics, and engineering. This can be presented as indices and matrices. These theories and tools usually apply to human behaviour. The same application is made to technical and physical systems. Systems dynamics draws on economics, cognitive, social psychology in addition to social sciences. System dynamics models are designed to solve real world problems [7]. According to [8] real life systems are based on deliberate human actions. These human actions are augmented by technology, complex reasoning, and organisation. The evolutionary process is much longer than the time scale of change imposed by humans. Ecosystem's principles alone within the groundwater models (figure 1) are not sufficient for dealing with human systems and its sustainability. For this reason, all aspects under study of a sustainability system are given equal weighting. Complexity is embraced as opposed to a reductionist approach.

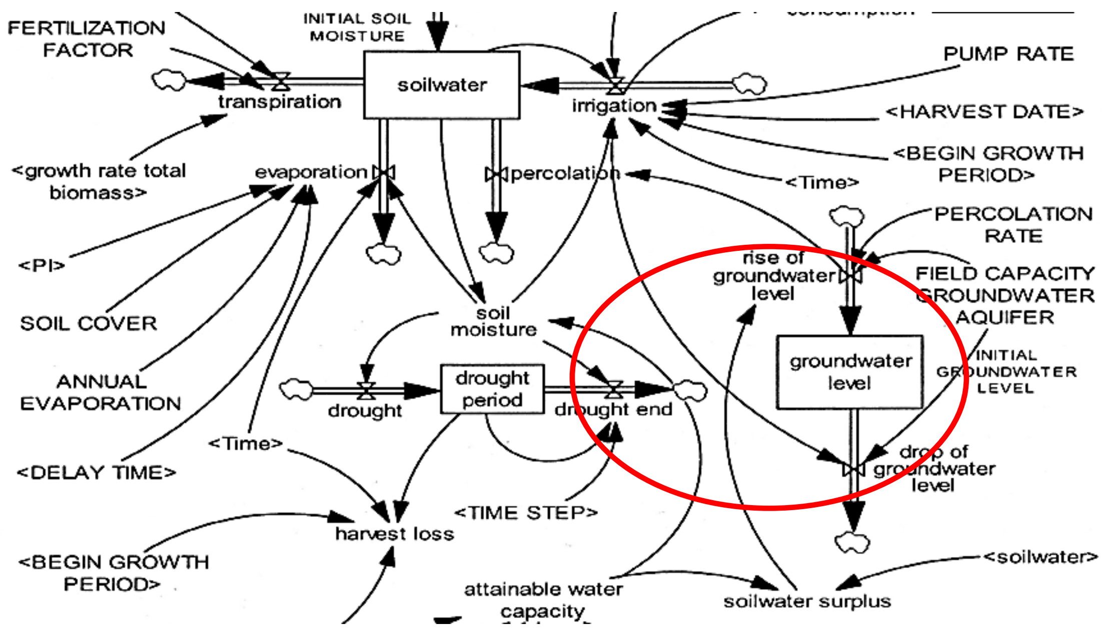


Figure 1: Simulation of an aquifer's water balance. Source:[8]

1.2 Factors affecting catchment groundwater sustainability

[9] described three types of rainfall: orographic, cyclonic and conventional. Orographic rainfall is because of airstreams forced to rise over a mountain range at which place the air is cooled. After this action rains falls. The orographic effect has been under pinned to the windward slope of large topographical configurations typically receiving more rain than the leeward slope [10]. Cyclonic rainfall forms when warm air rises over cold air. The cold air condenses the warm air, and the cooling effect results in colds and later rainfall. Convectional rainfall is synonymous with the tropical climate. Its formation is because of rising and abrupt cooling of hot air. The hot ground is responsible for this heat exchange. The degree of heat determines if there will be thunderstorms. Convectional rainfall registers the highest amount of rainfall therefore more potential recharge to percolate in groundwater stored in an aquifer. Rainfall is an important groundwater sustainability factor because its key to assessing any rainfall-runoff models [11]. The availability of precipitation data and its duration are vital for hydrologic analysis during design and management of water resources systems [12].

Topography defines the formation of land surface. This includes its relief and the position of its natural and man-made features[11];[13]. Topographic maps are usually used to show areas of different elevations in a place. The elevations of mountains and valleys, steepness of slopes, and the direction of stream flow can be determined by studying topographic maps [11]; [14]. Topography is a key factor in groundwater sustainability because hydrologists use topographic and soil maps to understand an area [11];[15];[16]. In groundwater sustainability, topography dictates the direction of groundwater flow. Topography also affects groundwater recharge and discharge [11];[13]. The impact of topography on rainfall distribution can be linked to different mechanisms, such as wind-driven effects and the small-scale topographic effect [10]. Topography is known to contribute to base flow after the water table of groundwater in an aquifer has been satisfied. Larger slopes generate more speed than smaller slopes. This can create faster runoff faster. Smaller slopes, balance rainfall input and the runoff rate that get stored temporally over the area. With time it can drain out gradually. This is an important consideration for groundwater sustainability. [11]; [16]; [17] as well as [18] reported that arise in surface slope showed a rise in surface runoff. More runoffs mean less accumulation of groundwater in aquifer.

Land cover refers to natural vegetation cover and the human impact through several activities that are directly related to land occupation. Human activities make use of land resources and interferes in the ecological process that determine the functioning of land cover [11];[[18]. Land cover and therefore land use is one of the key parameters in groundwater sustainability, particularly in the hydrologic cycle [11];[19]. The effect of land use change, land cover change and urbanisation on the hydrologic modalities and processes in catchments was studied in terms of vegetation conversion during the 1980s and 1990s [11]; [19]. In an investigation carried out by [20], it was found that urbanization led to a 2.9% rise in the peak flow. In addition, a decrease of 14% on peak flows due to increased afforestation was also reported by [20] reported a 5% - 12% increase on runoff due to urbanization. [21] found that urbanization causes an increase of storm flows in relation to the increased amount of surface runoff. Land cover is proportional to groundwater accumulation into an aquifer.

Soil is an important factor for ground water sustainability. The texture of a particular soil, says a lot about the hydraulic conductivity, the soil particle size distribution in a sample of the soil [11];[22];23]. Soil texture and coarse fragment content are most important properties for groundwater sustainability. This is because it affects water flow through the soil. In addition, it also sets out the amount of water retained in the soil, contributing to the water table of the aquifer in a catchment [11];[24]. Different soil types affect runoff characteristics and generation. In an analysis of Trinidadian soils, [25] reported the mean runoff values of: 22.2 mm, 22.9 mm and 40.9 mm for the loamy sandy, loamy clay and clay soils respectively. For example, clay soil has the highest value compared to sandy soil.

2. Methodology

2.1 The study area

The C52 catchment is in the Karoo basin of South Africa. Groundwater in the Karoo is found in contact zones of dykes, sills, intrusive rocks, and weathered rock sections [26]. The major rock types underlying the C52 catchment are dolerite, mudstone, sandstone, and shale. The geology comprises of the Ecca group and the Beaufort group [26]. The groundwater yield of the Karoo basin is generally limited (0.3 l/s), except in some areas where large volumes are pumped to supply towns and mines [27]. A comprehensive description regarding the Modder River catchment is given by [28]. The total area is at 1 736 000 ha, with a mean annual precipitation (MAP) of 537 mm. The delineation of C52 establishes a total catchment area of 949 km2. The mean annual runoff (MAR) from the total area is estimated at 94.42 × 106 m3. Of the 1 736 000 ha, around 70 000 ha is communal land occupied by subsistence farmers with a low standard of living. Figure 2 shows the outcome of the delineation process. For the aquifer supporting C52 delineation was done with the participation of Department of Water and Sanitation affairs staff to define boundaries and divide the study area C52.

Figure 2: Map showing the study area C52 as marked (data source BKS)

2.2 CARS conceptual framework for sustainable groundwater in catchment management

There are several physical processes governing hydrological cycles in relation to groundwater sustainability in an aquifer. Some of these processes are surface to groundwater interactions, land use to groundwater interactions and land use and climate interactions. A conceptual framework helps to represent these processes as factors. For this paper the factors were grouped as CARS: climatic, aquifer sustainability, right/equity of resources and socio-economic (see figure 3). This is set within the context of the environment, economy and society, which are all at play in the catchment. Sustainability is a link between hydrological interactions. Water is extracted from an aquifer through well pumping which is because of land use activity. Ownership and rights effectively shortcuts the natural processes of recharge as the land are used. The amount of groundwater recharge and discharge in an aquifer is important to groundwater sustainability within this conceptual framework. The conceptual framework was designed to trace the major relationships and interactions within the groundwater system in an aquifer that serves a catchment. This conceptual framework supports the making of inductions, deriving concepts from the data. It is also linked to the making of deductions directed at hypothesising the relationships between processes governing groundwater within the CARS framework.

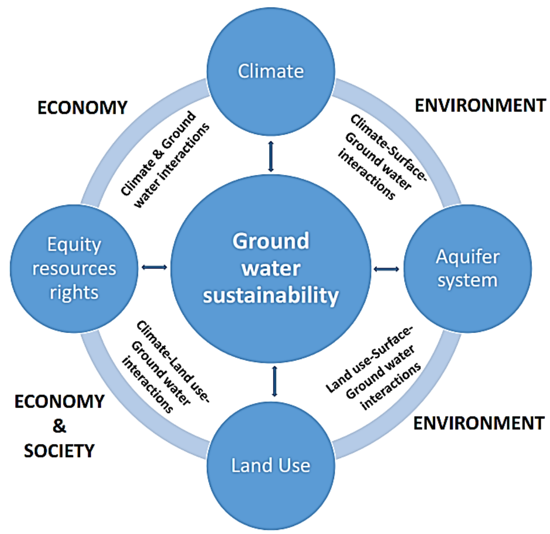


Figure 3: Conceptual framework supporting CARS.

2.3 Proposed rating of hydrological parameters

These ratings involve the assignment of values to the overall elements in factors C, A, R and S as follows:

Factor (C) climate: Rainfall is assumed as critical in the catchment hydrological processes. It is given the maximum score value of five to areas exceeding 3000 mm, and the lowest score of one to areas receiving less than 400 mm of rainfall. A similar approach is taken to assigning the maximum and minimum score to evapotranspiration, sunshine, slope, vegetation, and climate zones these figures are from metrological centres. In regions where the amount of rainfall is annually very low (<400 mm/year), the lowest score value will be assigned. In general, when the rainfall rate is higher than the infiltration rate, the rainwater is likely to run off rather than infiltrate to recharge in aquifer thus stored as groundwater. This will also depend on the nature of the surface topography. For factor C, the slope/topography is derived from the differences in contour values. Based on the slopes, score was assigned as shown in table 1. Lowest scores of 1 correspond to areas with the highest slopes greater than 50. These areas will encourage run-off and lower infiltration, while lowest slopes of zero to 5 correspond to areas with contours equal to that of water bodies, which encourage ponding. This means more infiltration and a high score of 5 assigned. Slope/topography is derived from the difference between the highest topographic points to the lowest topographic point of an area. Run-off, infiltration, and recharge are influenced by the areal slope. Areas of low slope encourage ponding and retain water for a longer period, thereby increasing the possibility of percolation and infiltration and increase the potential for contaminated water migration. More run-offs occur in areas with steep slopes and low infiltration. This reduces the possibility of groundwater contamination. Flat slopes are prone to flooding and groundwater contamination because ponded surface water will readily infiltrate to groundwater. In summary the equation that represents the evaluation of factor C is:

$$C = \sum_{k=0}^{n} k \qquad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\; equation\ 1$$

Where C is the total score of all the parameters considered under factor C.
k is the score of the parameter.

Table1: Idealised illustration Factor C

Rainfall (mm)	Score
>3000	5
1600-1200	4
1200-800	3
800-400	2

<400	1
Evapotranspiration (m	**Score**
>200	1
200-150	2
150-100	3
100-50	4
<50	5
Sunshine (centigrade)	**Score**
0-5	5
5-10	4
10-25	3
25-50	2
>50	1
Slope / Topography (m)	**Score**
0-5	5
5-10	4
10-25	3
25-50	2
>50	1
Climatic zones	**Score**
Desert	1
Arid – semi arid	2
Temperate	3
Monsoon	4
Tropics	5
Vegetation	**Score**
Tropical forest	1
Temperate forest	2
Savanah Grassland	3
Semi dessert shrub	4
Dessert shrub	5

Factor (A) aquifer sustainability : The pattern of groundwater recharged is found to be upstream supported by discharge downstream. Precipitation is higher to mountain peaks; it is also at these points that higher recharge occurs as compared to low laying plains. Low laying levels of groundwater discharges in valleys and other low-lying parts of the earth. Aquifers are defined by their rock types. A score of five was assigned to intergranular rocks due to the expected longer time it will take for water to infiltrate into the underground water (see table 2). Water percolating dense consolidated rocks is assumed to flow as surface run-off or subsurface horizontal flow, rather than as vertical infiltration flow, irrespective of the permeability of the topsoil. The dolerite presents the lowest percolation in all geological rocks and the infiltration is due to the small pore spaces and lower permeability present in most of them. The dolerite formation is given a low score of 0.5. Generally, the values corresponding to the scores are got from global reports and databases. During analysis of the Modder catchment values that are applied are got from data bases of Department of Water and Sanitation Affairs. In summary the equation that represents the evaluation of factor A is:

$$A = \sum_{k=0}^{n} k \qquad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots equation\ 2$$

Where A is the total score of all the parameters considered under factor A.
k is the score of the parameter.

Table 2: Idealised illustration Factor A

Aquifer system	**Score**
Unconfined	5
Perched	4
Confined	3
Semi confined	2
Fractured	1

Rock type / lithology		Score
Intergranular	0-5	5
Fractured	5-10	4
Karst	10-25	3
Intergranular fractured	25-50	2
Dolomite	>50	1
Water quality		**Score**
Smell		(yes=1, no =5)
Taste		(yes=1, no =5)
Colour		(yes=1, no =5)
Aquifer yields of the catchment (l/s		**Score**
>1		5
1-0.8		4
0.8-0.6		3
0.6-0.4		2
<0.4		1
Recharge (mm/year)		**Score**
<2		1
2-20		2
20-100		3
100-300		4
>300		5
Storage volume of aquifer (1000 meters)		**Score**
>1,000,000		5
1000000-800000		4
800000-600000		3
600000-400000		2
<400000		1

Factor (R) rights and equity verse resources: Rights and equity to resources define the characteristics in an aquifer. Number of permits issued in the catchment per year is assumed to be on importance because it represents the abstraction activity in the catchment. The maximum score value of five to number of permits less 1, the lowest score of one to areas receiving more than five permits. The same is considered in assignment of scores for the duration of permits, number of boreholes and pump rate. Based on global reports and data bases the values and score were assigned as shown in the table 3 with the lowest scores corresponding to poor practises and the highest score of 5 to mean good practices. During analysis and application of CARS on the Modder catchment, the figures are got from Department of Water and Sanitation Affairs data bases. In summary the equation that represents the evaluation of factor R is:

$$R = \sum_{k=0}^{n} k \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots equation\ 3$$

Where R is the total score of all the parameters considered under factor R.
k is the score of the parameter.

Table 3: Idealised illustration Factor R

Number of permits issued in the catchment per year	Score
<1	5
1-2	4
2-3	3
3-4	2
>5	1
Length or duration of permit years	**Score**
0-5	5
5-10	4
10-15	3
15-20	2

20	1
Number of boreholes in the sub catchment	**Score**
0-25	5
25-50	4
50-75	3
75-100	2
>100	1
Pump rate (1000 cubic meters per year)	**Score**
>1,000,000	1
1000000-800000	2
800000-600000	3
600000-400000	4
<400000	5

Factor (S) socio economics: Human activity affects an aquifer as such use per capita of the catchment is assigned the maximum score of five to a useless that 25l/c/d which is a good practice of little use of water. A per capita use of more than 100 is assigned a score of less than 1. This is the lowest score, and it indicates over abstracting or using too much water. The scoring for population in the catchment, water uses and tariffs, takes the same trend as per capita use. These values/ figures are from global reports and data bases. However, in terms of analysis of Modder catchment, the values assigned are derived from Department of Water and Sanitation Affairs data bases. Based on this data score were assigned as shown in the table 4 with the lowest scores corresponding to poor practises while the highest greater of 5 denotes a good practice. In summary the equation that represents the evaluation of factor A is:

$$S = \sum_{k=0}^{n} k \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textit{equation } 4$$

Where S is the total score of all the parameters considered under factor S.
k is the score of the parameter.

Table 4: Idealised illustration factor S

Use per capita of the catchment (l/c/d)	**Score**
<25	5
25-50	4
50-75	3
75-100	2
>100	1
Population in the catchment	**Score**
>2,000,000	1
2000000-1500000	2
1500000-1000000	3
1000000-500000	4
<500000	5
Water uses (l/d)	**Score**
Domestic (<2)	5
Afforestation (2-20)	4
Mining & bulk industrial (20-100)	3
Irrigation (100-300)	2
Power generation (>300)	1
Tariffs (rand)	**Score**
<2	5
2-20	4
20-100	3
100-300	2
>300	1

2.4 CARS sustainability index

CARS stands for climatic conditions, aquifer sustainability/system, rights/resources and socioeconomics. The overall objective of CARS is to assess sustainability of groundwater management in an aquifer in a catchment through analysis of a hydrological model, using predetermined parameters. It is therefore a major decision support system in the development of sustainability analysis methods. It considers the availability of input data for the hydrogeological system under consideration. The developed sustainability method targets the assessment of resources locally, regionally, and globally. The CARS methodology requires in depth understanding of the parameters and ranking of the physical processes affecting groundwater system of the Modder catchment. These include the climatic factors (precipitation, evapotranspiration, sunshine, slope, topography, and climatic zones), aquifer system (recharge, yields, storativity, aquifer types, and lithology/rock types). The CARS methodology looks at how these factors work together and relate to give a picture of the status of sustainability in a catchment. The CARS formula includes human induced parameters such as are rights and equity. These human factors include (number of issued permits per year in the catchment, duration of the permits, number of boreholes in the sub-catchment, pump rate per year), socio-economic and land use (use per capita, population in the catchment, water uses and tariffs).

Sustainability $S = \sum C+A+R+S$
Where:
C = Total score of the climatic condition factor
A = Total score of the aquifer sustainability factor
R = Total score of the rights/equity factor
S = Total score of the socio-economic factor

C and A have a scoring of 30 each, while R and S have a scoring of 20 each.

The final sustainability factors were added up because they all impact groundwater and therefore aquifer sustainability. C and A elements (aquifer sustainability and climatic conditions) are complex in the natural context, and therefore responsible for percolation and infiltration. As with the previously discussed principles of sustainability analysis all factors have equal weighting. A carries equal score with C because the sustainability methods assume rainfall evapotranspiration, sunshine and slope: as the principle climatic condition and initiator of the infiltration and later percolation process which contributes to recharge and later becomes groundwater. The implication is that if rainfall is absent and there is no groundwater formation. R and S impact on groundwater sustainability may be higher on analysis as human activity will deplete whatever groundwater is available and not replenish it. For this reason, the scores of the two are the same. Note is taken to group the sustainability Index into five classes. The classes and sustainability values are presented in figure 5. The final groundwater sustainability index class score of 19-35 means a class of very low sustainability, 35-51 means a class of low sustainability, 51-67 means a class of moderate sustainability, 67-83 means a class of high sustainability and 83-100 means very high sustainability. The sustainability index acronym is derived from the initial letters of the factors used in the formula: CARS. The sustainability index method is designed for onsite groundwater sustainability assessment and is accompanied with a spreadsheet (see table 5) that can calculate the sustainability impact. There are challenges when using the most established data to assess areas. As such the developed sustainability method has been designed to use few climates based hydrogeological parameters, fuzzy logic parameters such as rights and social economic data to assess groundwater sustainability of a delineated catchment like the C52. Delineation exercise caters for inflows and outflows from the catchments and caters for others processes that affect the characteristics of a sub catchment. This allows for identification of a unit of analysis such as the C52 that is representative of the rest of the lager catchment such as the Upper Orange.

3. Results

3.1 CARS application to C52 catchment of Modder River system

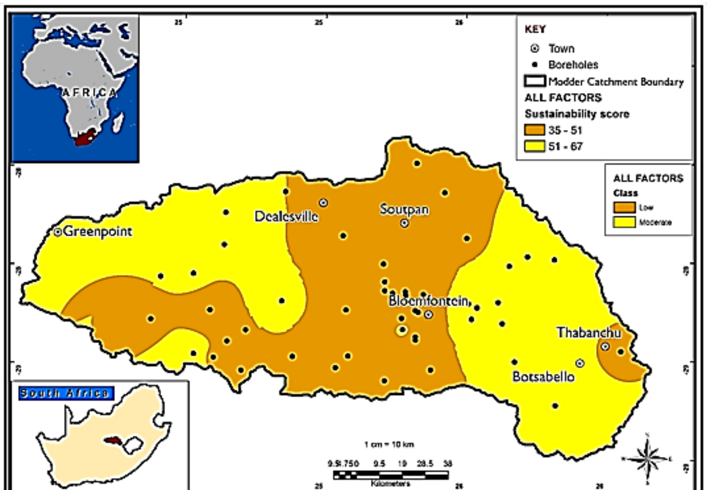
The rankings are based on a scoring system (see table 5) from the highest score of 100 which implies highly sustainable aquifer to the lowest score of 19 which suggest the least sustainable aquifer condition.

Table 5: Scoring of the CARS factors

Borehole	Latitude	Longitude	Score A	Score B	Score C	Score D	Sustainability Index	Sustainability Class
1	-28,867897	26,302778	14	10	7	11	42	LOW
2	-29,567891	26,072222	14	9	7	11	41	LOW
3	-29,098889	26,058333	14	9	8	11	42	LOW
4	-29,014567	26,144565	14	8	9	11	42	LOW
5	-29,012578	26,075565	14	8	7	11	40	LOW
6	-29,005556	26,025898	14	8	7	11	40	LOW
7	-29,292361	26,166667	14	9	7	11	41	LOW
8	-29,076946	26,120568	14	9	8	11	42	LOW
9	-28,995833	25,995833	14	10	7	11	42	LOW
10	-29,168446	26,112233	14	8	11	11	44	LOW
11	-29,075321	26,113345	14	10	10	11	45	LOW
12	-29,067528	25,850528	14	10	7	11	42	LOW
13	-29,182341	26,110765	14	5	11	11	41	LOW
14	-29,239611	25,857694	14	8	7	11	40	LOW
15	-29,283324	25,811056	14	8	7	11	40	LOW
16	-29,332056	25,994028	14	7	8	11	40	LOW
17	-28,519876	26,116667	14	10	7	11	42	LOW
18	-28,896223	25,991389	14	10	7	11	42	LOW
19	-29,007389	-29,007389	14	7	7	11	39	LOW
20	-28,791234	25,849082	14	7	10	11	42	LOW
21	-29,066667	25,341667	14	8	7	11	40	LOW
22	-28,962778	25,995833	14	8	7	11	40	LOW
23	-28,633241	26,220044	14	8	8	11	41	LOW
24	-29,223557	26,878324	14	8	10	11	43	LOW
25	-29,141083	26,062083	14	9	7	17	47	LOW
26	-29,425139	26,632917	14	9	10	17	50	LOW
27	-29,262148	26,480619	14	7	11	17	49	LOW
28	-28,973456	-28,978757	14	7	7	16	44	LOW
29	-28,904639	26,462567	14	9	7	16	46	LOW
30	-28,880806	26,630833	14	9	7	16	46	LOW
31	-28,876754	26,535642	14	9	11	16	50	LOW
32	-29,046543	26,425678	14	9	11	16	50	LOW
33	-29,044944	26,308056	14	10	11	15	50	LOW
34	-29,063256	26,345673	14	8	7	15	44	LOW
35	-29,103864	-29,103089	14	8	7	15	44	LOW
36	-29,102778	26,320278	14	9	11	15	49	LOW
37	-29,118826	26,434841	14	9	11	15	49	LOW
38	-28,551254	25,373452	14	9	7	15	45	LOW
39	-28,625321	25,625765	14	9	7	15	45	LOW
40	-29,243806	25,354222	14	8	7	15	44	LOW
41	-28,941111	25,157778	14	9	7	15	45	LOW
42	-29,233333	25,284567	14	9	11	15	49	LOW

43	-29,122222	25,120872	14	8	7	15	44	LOW
44	-28,702785	25,401392	14	9	11	15	49	LOW
45	-29,182972	25,405139	14	8	7	15	44	LOW
46	-28,822567	25,395757	14	9	8	15	46	LOW
47	-29,291972	25,457528	14	8	7	15	44	LOW
48	-29,141667	25,475567	14	9	7	15	45	LOW
49	-29,241667	25,654352	14	9	7	15	45	LOW
50	-29,033861	25,609833	14	13	7	15	49	LOW
51	-28,936565	25,283421	14	11	7	15	47	LOW

The climatic conditions, rights and equity as related to the groundwater resources, socio economics and the aquifer system sustainability scores were generated. Sources of data and their application were from Department of Water and Sanitation Affairs. The result of the CARS methodology application to evaluate the sustainability of the aquifer in the C52 Modder River catchment presented the moderate to low classes of sustainability. This means that the Modder River basically has areas with too much abstraction activity, unfavourable climatic condition and slow to little groundwater recharge processes and interactions. This further suggests high or steep slopes and low rainfall. The moderate sustainability class are characterised by extensive dolerite, low recharge, and low slope as well. The final sustainability map (Figure 4) was derived from the sustainability index calculations, which was computed, based on the principles behind sustainability by combining the factors of climatic conditions, rights and equity as related to the groundwater resources, socioeconomics, and the aquifer system sustainability.



Sustainability index	Sustainability class	Colour code
19-35	Very low	Red
35-51	Low	Orange
51-67	Moderate	Yellow
67--83	High	Green
84-100	Very high	Blue

Figure 4: The final groundwater sustainability map of the Modder River catchment. Source: Author

4. Conclusion

In conclusion, the sustainability class presented in the Modder River aquifer catchment ranges from low sustainability to moderate sustainability. Based on this it's fair to say the CARS methodology is a simplified concept, the sustainability index method makes use of both the subjective and physically based techniques. In the field, infiltration, and percolation of rainfall less evapotranspiration is assumed as recharge under steady state conditions. The sustainability class is similar to that of other methods used for assessment where scores are applied. For instance, the sustainability classes range from very low to very high sustainability. The sustainability index parameters for evaluation are easy to collect, collate and calculate, and is designed for data accessible widely globally.

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