CONCEPTUAL HYDROGEOLOGICAL MODEL OF THE CENTRAL KALAHARI BASIN

BOTSWANA GEOcientISTS ASSOCIATION PUBLIC LECTURE

VENUE: THAKADU HOTEL, LETLHAKANE

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BASED ON:

PRESENTATION OUTLINE

- INTRODUCTION
- MOTIVATION
- OBJECTIVES
- STUDY AREA AND DATA DESCRIPTION
- METHODS
- RESULTS AND DISCUSSION
- CONCLUSIONS
INTRODUCTION

- Hydrogeological Conceptual Model (HCM) summarize hydrogeological knowledge of the site to be modelled numerically.

- It provides the framework for numerical model development.

- HCM constructed from surface and subsurface data to help hydrogeologists to understand the hydrogeological system behavior and to support quantitative numerical modelling.

- Schematize a hydrogeological system of layers into hydrostratigraphic units and associate boundary conditions, hydrogeological properties, driving forces, state variables, flow directions and preliminary water budgets.

- Different methods to setup HCMs exist, involving analysis and integration of relevant geological and hydrogeological data
  - E.g. using database tool such as geographical information system (GIS)
  - modelling environments with inbuilt 3-D geological modelling capacity.

- There is no standard widely accepted methodology in developing a HCM.
• A robust hydrogeological model need to be developed from a realistic HCM.

• To manage subsurface data, in this study, 3-D geological modelling software tool was used in developing the HCM.
  
  – Able to intergrade geological and hydrogeological heterogeneity with structural fabric.

  – Also provide a check on the logic of a hydrogeological conceptualization.
The Central Kalahari Basin (CKB) host the most productive aquifers in Botswana
OBJECTIVES

• Development a regional hydrogeological conceptual model of the CKB to improve understanding on:
  
  – Spatial distribution of the CKB hydrostratigraphic units.
  
  – Effects of regional faults and basin morphology on hydrostratigraphic units, spatial aquifer parameter distribution, hydraulic heads and groundwater flow pathways.
STUDY AREA AND DATA

LOCATION & PHYSOGRAPHY

- CKB with ~181,000 Km² in Botswana and ~14,000 km² in Namibia.
- Large-scale hydrogeological basin.
- Currently nearly flat due to accumulation of eolian sand. ~90% being desert.
- Semi-arid to arid with convectional rainfall
- Rainfall: 250 – 550 mm yr⁻¹ (Sep – April)
- Winter temperature range between 6°C – 25°C and summer has average Max 35°C

potentiometric surface on 31 December 2006
About 2/3 of the CKB is occupied by Kalahari Karoo Basin (KKB) and 1/3 occupied by Pre-Karoo rocks.

Pre-Karoo are:
- Ghanzi, Waterberg and Transvaal Super Groups

KKB is a sedimentary basin type structure extending over most of SADC countries

In Botswana, KKB is divided into:
i. Kweneng
ii. Mmamabula
iii. SE Central Kalahari
iv. N Belt Central Kalahari
v. SW Central Kalahari
vi. W Central Kalahari sub-basins

Karoo Supergroup Formation, in which GW resources in CKB occur, Subdivided into:
- Stormberg Basalt Group
- Lebung Group
- Beaufort Group
- Ecca group
- Dwyka Group
The Pre-Kalahari Group geology of the Central Kalahari Basin, modified after Key and Ayres (2000) and Carney et al. (1994).
Principal aquifers in CKB are:
- Ntane and Nakalatlo Sandstones (Lebung Aquifer).
- Ecca Aquifer
- Ghanzi Aquifer

Regional GW flow has radial concentric pattern towards Makgadikgadi Pans outflow.

Recharge is incidental, restricted to very wet years/seasons, occurring every 5-10 yrs.
- Long term mean recharge range from 5 - 10 mm/year in the fringes to < 1 mm/year in CKB central.

Groundwater abstraction mainly in the fringes of the CKB.
## STUDY AREA AND DATA CONT.

Stratigraphy and hydrostratigraphy of Karoo Supergroup in the CKB, modified after Smith (1984) to include Pre-Karoo and Kalahari Rocks

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>Period</th>
<th>Karoo Division</th>
<th>Group</th>
<th>Sub-Basin</th>
<th>Hydrostratigraphy</th>
</tr>
</thead>
<tbody>
<tr>
<td>CENOZOIC</td>
<td>Quaternary</td>
<td>Post-Karoo</td>
<td>Kalahari</td>
<td>Kalahari Group</td>
<td>Kalahari Sand Unit (KSU) (Unit 1)</td>
</tr>
<tr>
<td>MESOZOIC</td>
<td>Jurassic</td>
<td>Upper Karoo</td>
<td>Stormberg Basalts</td>
<td>Stormberg Lava Group</td>
<td>Stormberg Basalt Aquitard (SBA) (Unit 2)</td>
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<tr>
<td></td>
<td>Triassic</td>
<td>Upper Karoo</td>
<td>Lebun</td>
<td>Ntane Sandstone Formation</td>
<td>Lebun Aquifer (LA) (Unit 3)</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Mosolotsane Fm.</td>
<td>Mosolotsane Fm. (North East Only)</td>
<td>Inter-Karoo Aquitard (IKA) (Unit 4)</td>
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<td></td>
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<td>Pandamatenga Fm.</td>
<td>Dondong Fm.</td>
<td>Ecca Aquifer (EA) (Unit 5)</td>
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<tr>
<td>PALEOZOIC</td>
<td>Upper Permian</td>
<td>Beaufort</td>
<td>Beaufort Fm.</td>
<td>Kvetla Fm.</td>
<td>Ecca Aquifer (EA) (Unit 5)</td>
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<td></td>
<td>Lower Permian</td>
<td>Lower Karoo</td>
<td>Mmamabula Fm.</td>
<td>Korotli Fm.</td>
<td>Ghanzi Group</td>
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<td></td>
<td>Serowe Fm.</td>
<td>Tiapana Fm.</td>
<td>Ghanzi Aquifer (GA) (Unit 6)</td>
</tr>
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<td></td>
<td></td>
<td>Boritse Fm.</td>
<td>Otsho Fm.</td>
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<tr>
<td>PROTEROZOIC</td>
<td>Mesoproterozoic</td>
<td>Dwyka</td>
<td>Dwyka Fm.</td>
<td>Dukwi Fm.</td>
<td>Waterberg, Transvaal, Gaborone Granite, Kanye Formation, Okwa complex</td>
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<td></td>
<td></td>
<td>Middlepits Fm.</td>
<td>Khuis Fm.</td>
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<td>Malogong Fm.</td>
<td>Ghanzi Fm.</td>
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<td></td>
<td></td>
<td></td>
<td>Ghanzi Aquifer (GA) (Unit 6)</td>
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</table>
STUDY AREA AND DATA CONT..

DATA

• Boreholes log data from BGI

• Unpublished Government reports from BGI and DWS.

• Hydrogeological data from DWS and DEBSWANA and NAMIBIA

• 90 m SRTM DEM

• Geological shapefiles from BGI
STUDY AREA AND DATA CONT..

METHODS

Hydrostratigraphic Unit thickness + Major faults

Inverse distance power 2 interpolation

Hydrogeological parameters + Hydraulic heads

Hydrogeological parameters

ArcGIS maps

x-sections

XYZ thickness

ArcGIS maps

CKB HYDROGEOLOGICAL CONCEPTUAL MODEL
RESULTS

GEOLOGICAL MODELLING

- The Kalahari Sand Unit (KSU)
- Stormberg Basalt Aquitard (SBA)
- Lebung Aquifer (LA)
- Inter-Karoo Aquitard (IKA)
- Ecca Aquifer (EA)
- Ghanzi Aquifer (GA)

To present CKB flow systems, X-sections were drawn along sections of interest.
STUDY AREA AND DATA CONT....

X-Sections

Legend

- Kalahari Sand Unit
- Stormberg Basalt Aquitard
- Lebuaš Aquifer
- Inter-Karoo Aquitard
- Ecca Aquifer
- Ghanzi Aquifer
Aquifer hydrogeological properties

- KSU Not regarded as an aquifer.
- KSU Important on redistribution of recharge to underlying aquifers with $K_v$ ranging from 1.0 – 15 m/d
Flow system analysis in the Kalahari Unit

Groundwater flow systems and hydrogeological boundary conditions

- 3 possibilities considered
  - Lower KSU saturated and underlain by aquifers (solid), entirely unsaturated (dash).
  - Similar when underlain by Aquitards.

- The radial concentric flow pattern converge from W, E, S no-flow boundaries towards N Makgadikgadi outflow.

- The pattern match underlain aquifers where hydraulically in connection

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[Map showing groundwater flow systems and hydrogeological boundary conditions]
The radial concentric flow pattern converge from W, E, S no-flow boundaries towards N Makgadikgadi outflow.

At CKB peripheral zones, Lebung is hydraulically connected with KSU while its confined by SBA in the center.

These connections are likely reasons for similar of similar groundwater flow patterns as the overlying KSU.

There is vertical groundwater flow across the SBA between KSU and Lebung Aquifer.
Flow system analysis in the Ecca Aquifer

- Similar flow pattern as that of KSU and Lebung Aquifer.
- At CKB peripheral zones, Lebung is hydraulically connected with KSU while its confined by IKA in the center.
- These connections are likely reasons for similar of similar groundwater flow patterns as the overlying KSU.
- There is vertical groundwater flow across the IKA between Lebung and Ecca Aquifers.
- Localized cones of depression south of Zoetfontein fault
Schematic diagram for the CKB hydrogeological conceptual model
CONCLUSIONS

<table>
<thead>
<tr>
<th>Developed CKB hydrogeological conceptual model showed that:</th>
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<tr>
<td>• Possible Ecca and Ntane vertical interaction where hydraulically in contact.</td>
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<td>• Regional faults act as flow barriers pending further assessment with numerical modelling.</td>
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<tr>
<td>• Lebung and Ecca confined in the majority of the CKB.</td>
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<th>3-D geological model approach very important in development of hydrogeological conceptual models because:</th>
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<td>• It integrate all available data tests to develop meaningful model.</td>
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<td>• It is dynamic incorporating new data sets as they become available.</td>
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• BOTSWANA GEOSCIENCE INSTITUTE

• DEBSWANA
References


References


KEALEBOGA
THANK YOU