DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2018/39

Data processing for the Nasia basin model, GhanAqua project

Hydrostratigraphy, Topography and Groundwater recharge

Lars Troldborg & Millicent Obeng Addai

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
DANISH MINISTRY OF ENERGY, UTILITIES AND CLIMATE

G E U S

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Contents

List of Figures

Introduction

During September 2018 two Ghanaian PhD students, Millicent Obeng Addai and Fynn Fiifi Obed visited GEUS and KU at GeoCenter Denmark in Copenhagen. As a part of this visit data in the HAP database and data collected as a part of the GhanAqua project was processed to generate input for the hydrological model (GMS). This report summarize the data processing and resulting model layers for GMS, a groundwater recharge - and a groundwater elevation map. All data are processed in WGS 84 / UTM zone 30N projection (http://spatialreference.org/ref/epsg/wgs-84-utm-zone-30n/).

Conceptual model

Based on the GEUS notat on “Conceptualising the Nasia basin - summery of a HAP database review” the hydrostratigraphy can be subdivides into four different sections:

- Residual soil (usually sandy-clayey material possibly underlain by indurated layer, completely weathered)
- Saprolite (highly to moderate weathered rock with decreasing clay content with depth)
- Saprock (Slightly weathered with remnants of fresh rock in an altered matrix)
- Freshrock (largely un-weathered or fresh rock with some fractures)

The Residual soil and Saprolite (the Regolith), constitute the storage of the aquifer system, characterized with relative high porosity/specific yield and low hydraulic conductivity. The Saprock together with eventually fractured freshrock constitute the water bearing unit of the aquifer system, characterized by relative high hydraulic conductivity but little porosity (see Figure 1).

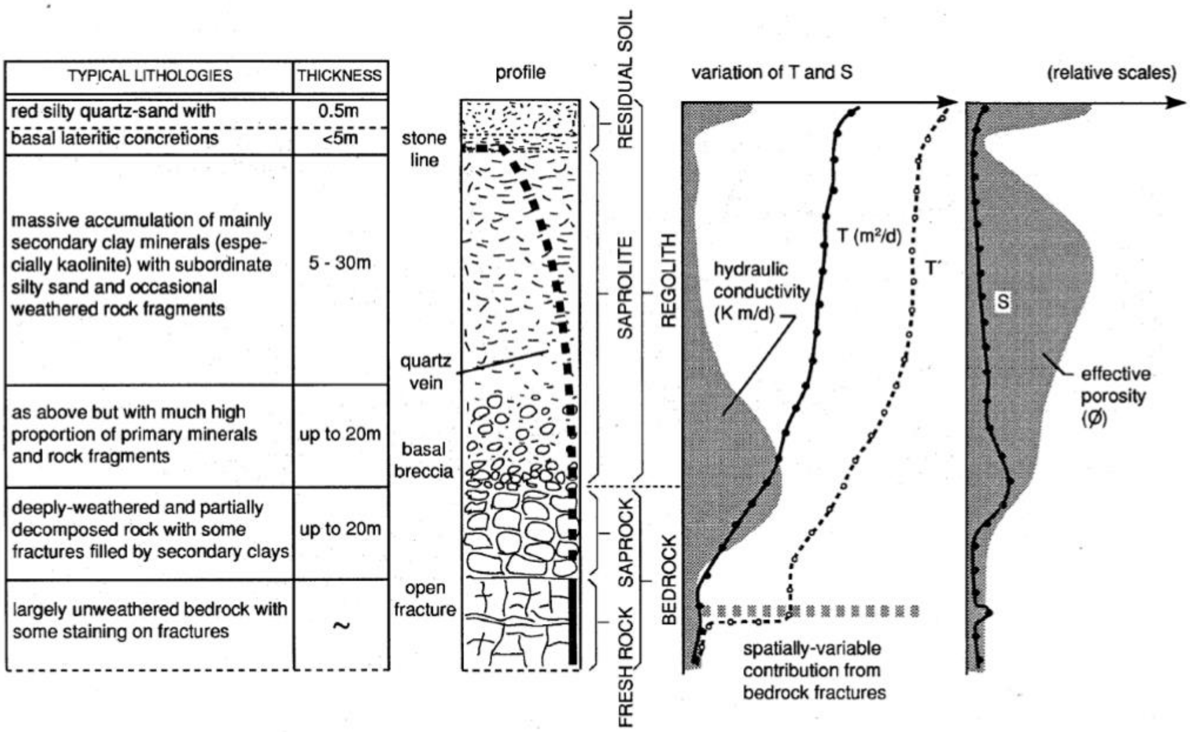

Figure 1 Conceptual model of weathered zone (figure from HAP report)

Hydrostratigraphic data

In the HAP database there are no sub-division into Saprolite, Saprock, but most of the data are characterized with respect to degrees of weathering, remnants of fresh rock and degree of fractures, and in the GeoScene3D geological model constructed by Eli and Flemming there are no interpretation of these four units, however, Eli and Samed together with Kurt Klitten has produced interpretation of the Regolith depth at 227 points based wire logging data and wells in the area.
For interpolating four hydrostratigraphic layers (RS: bottom of Residual soil, Saprock: bottom of Saprock, Saprolite: bottom of Saprolite and RF: bottom of fractured rock) each of two tables in the HAP database containing lithological interpretation (BoreholeLithology and BoreholeLithology_FromBoreholeLogging) was summarized into maximum depth of the four hydrostratigraphic units per well id (see Table 1 for information on HGUCodes used in summarizing).

Table 1 Summarize Lithological data from HAP database

Hydrostatigrafic unit	SQL select	Summery
Residual soil (RS)	HGUCode In ('RS')	‘Well ID’, max(‘depth’)
Saprolite	HGUCode In ('CW', 'CW-HW', 'CW-MW', 'HW', 'HW-MW', 'HW-SW', 'MW', 'MW-SW', 'RS-HW', 'RS-MW', 'RS-SW')	‘Well ID’, max(‘depth’)
Saprock	HGUCode In ('SW' , 'SW-RK' , 'MW-RK' , 'HW-RK')	‘Well ID’, max(‘depth’)
Fractured rock (RF)	HGUCode In ('RF', 'SW-RF', 'MW-RF', 'HW-RF')	‘Well ID’, max(‘depth’)
Bedrock	HGUCode In ('RK')	‘Well ID’, min(‘depth’)

The two summarized tables, that now holds information on depth of hydrostratigraphic units, was joined by well id to one combined table. From this a combined adjusted column per hydrostratigraphic unit of depth were calculated/interpreted: missing units from one table used units from the other, were maximum fracture rock depth was missing then minimum bedrock depth was used, and when both tables hold conflicting depth information then one of them were selected and a “note” was added. The final combined adjusted depth values were joined with the HAP “well” shape that among other things holds the well coordinates, thus producing a shape file with well location and hydrostratigraphic depths information (e.g. well id, utmX, utmY, RS_depth, Saprolite_depth, Saprock_depth, RF_depth).

Hydrostratigraphic layers

Interpolation

Sequentially, each of the hydrostratigraphic units with depth information was selected from the well shapefile and a depth grid (Figure 2 to Figure 5) was interpolated using these data. For the Saprolite depth grid, prior to interpolation, the 227 interpreted data points of Regolith depth was appended to the wells holding the Saprolite depth. Simple interpolation scheme was chosen rather than interpolation schemes that assumes a statistical correlation between the data points, primarily because of the scarcity of data with of the long distances between data points and secondary because of the large differences in depth in the dataset that seems to be correlated to spatial location suggesting in-stationarity must be expected in the depth data.
For the Saprolite depth the use of both HAP and Eli data does seem to have some overlap, but from the information stored with the depth interpretation it was not possible to distinguish if wells were identical or just close to each other.

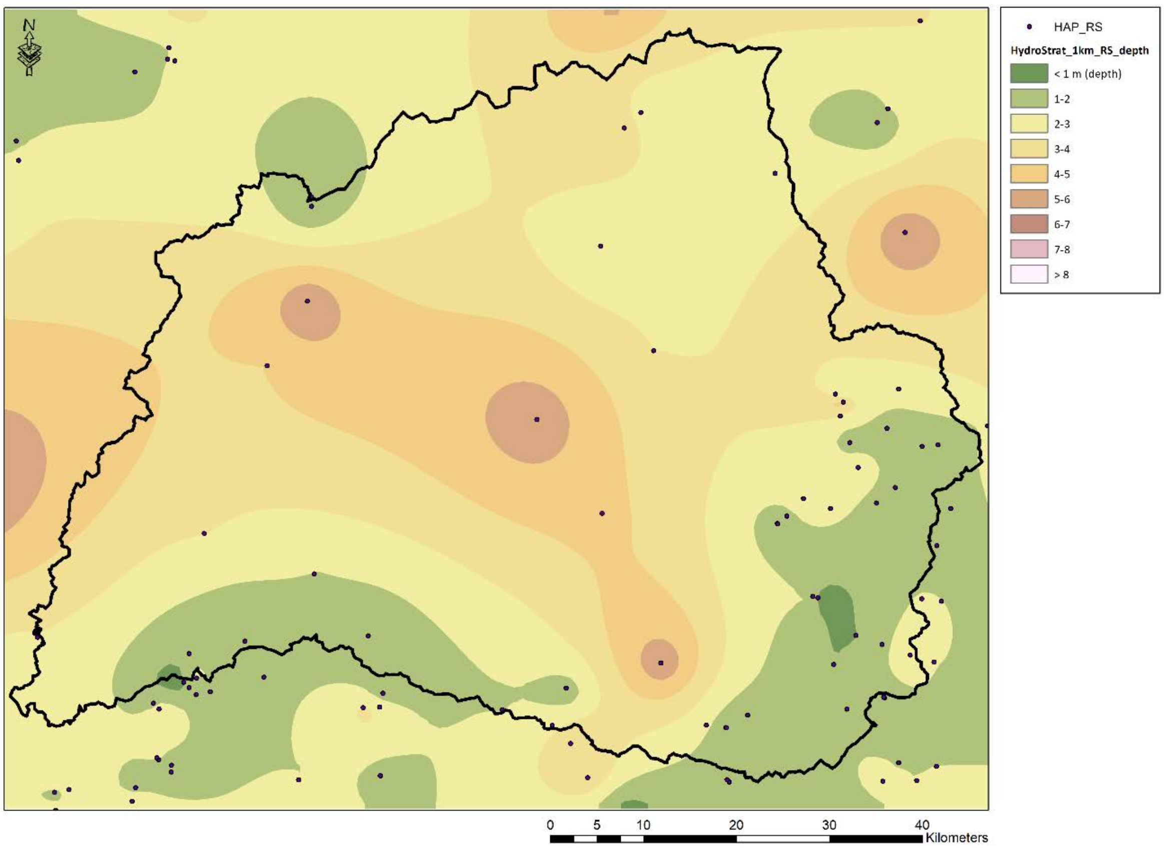

Figure 2 Interpolated Residual soil layer depth and depth observation data location

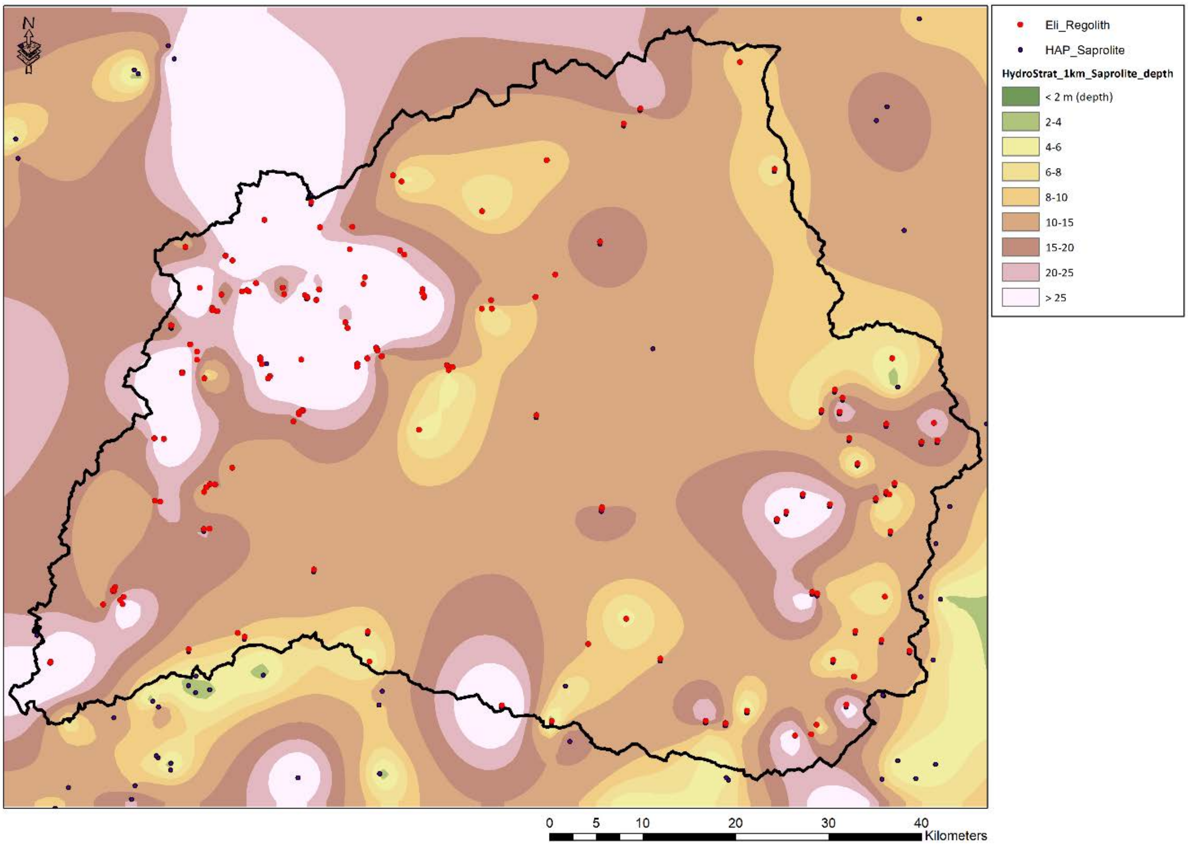

Figure 3 Interpolated Saprolite layer depth and depth observation data location

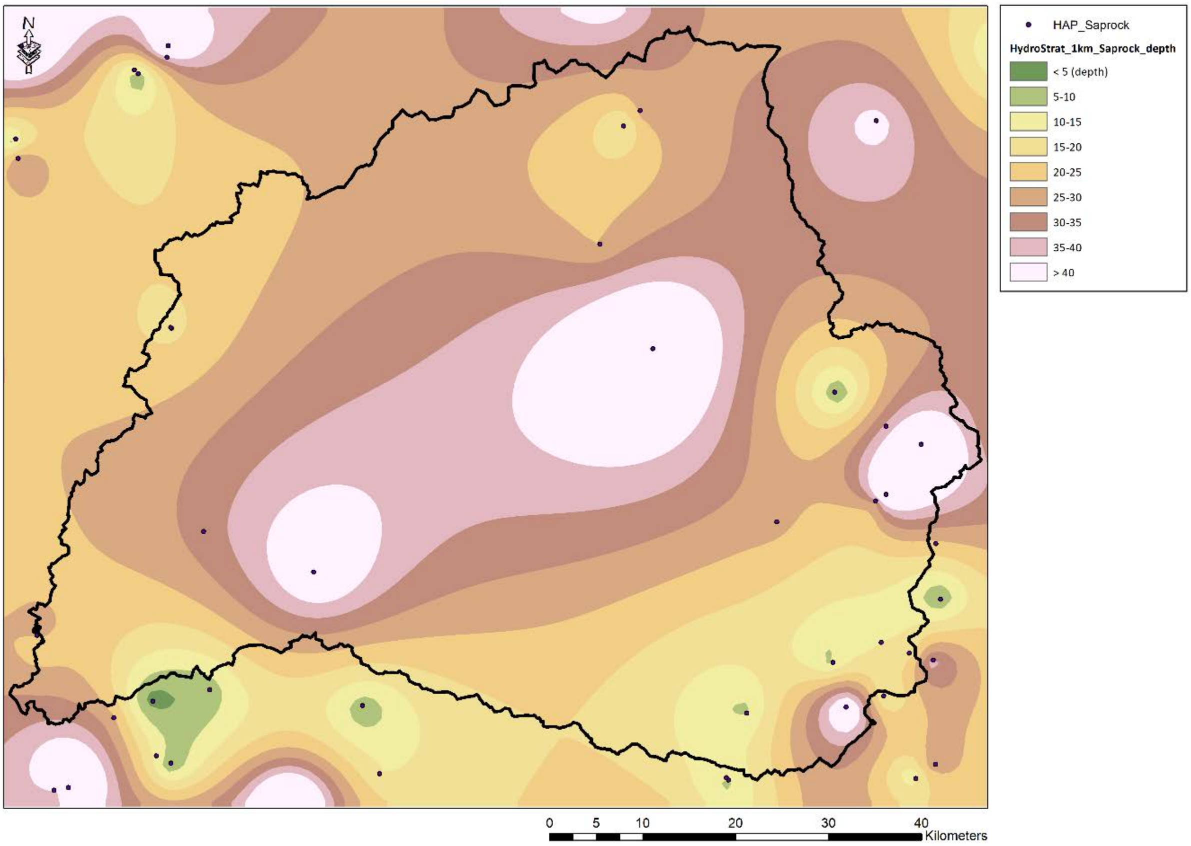

Figure 4 Interpolated Saprock layer depth and depth observation data location

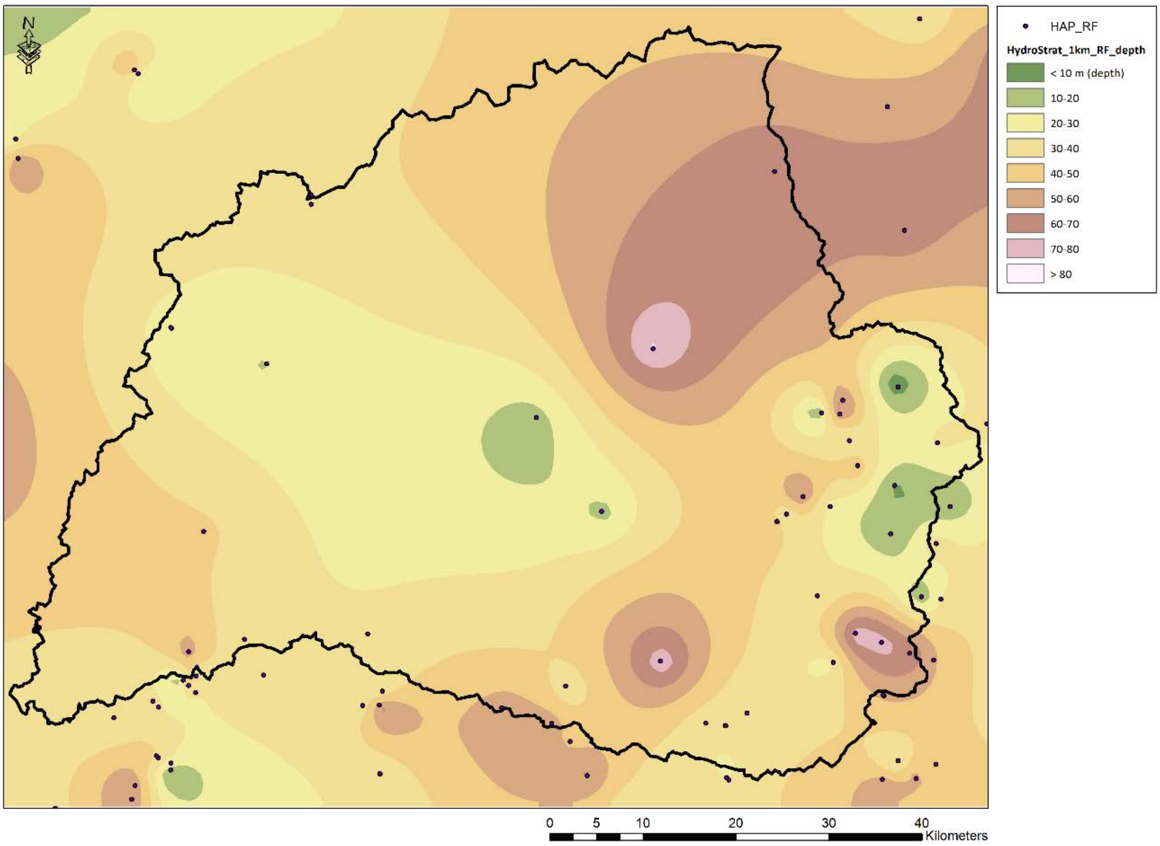

Figure 5 Interpolated Fractured Rock depth layer and depth observation data points

Thickness calculation

Calculation of thickness was done in two stages. Stage one thickness calculation was done substracting layer depth of the hydrostratigraphic unit just above from the layer depth of the investigated hydrostratigraphic unit plus adding a minimum thickness of 0.2 meter. Visual evaluation of first stage calculations with focus on areas of low and high thickness, data location and holes and peaks in the thickness leads to a conclusion:

1) RS and Saprolite (Figure 6 and Figure 7)
    a) No further work is needed
    b) More data points would be better, but the data will do so far
    c) Corroborates conclusion from prior work (Millicent report from Denmark stay in 2016) that relation between topography and geology are without clear conclusion
    d) Simple interpolation on depth preferred over interpolation on thickness or fixed thickness
2) Saprock and RF (Figure 8 and Figure 9)
    a) Critical areas of little thickness in areas of few or no datapoints
    b) Re-Interpolation on layer thickness should be attempted based sampled thicknesses (from current layer) at well location

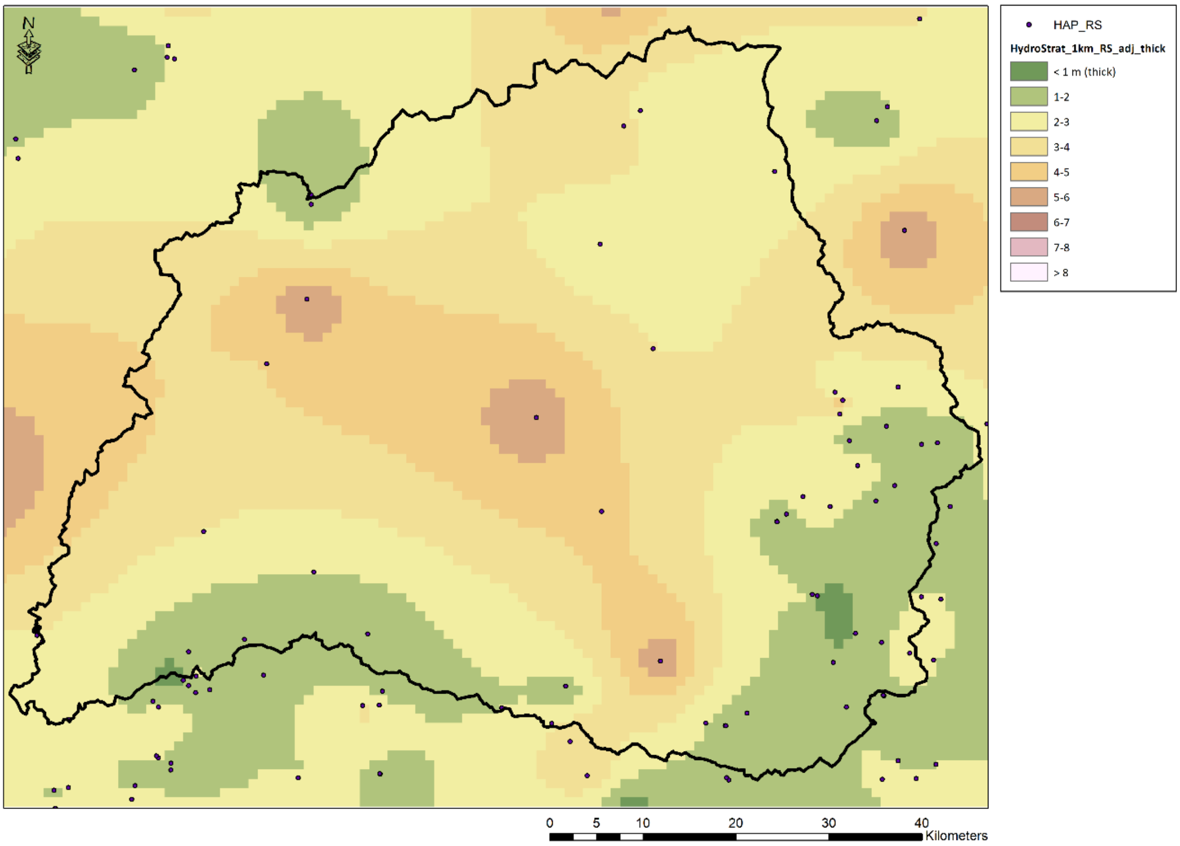

Figure 6 Calculated thickness of Residual soil (RS)

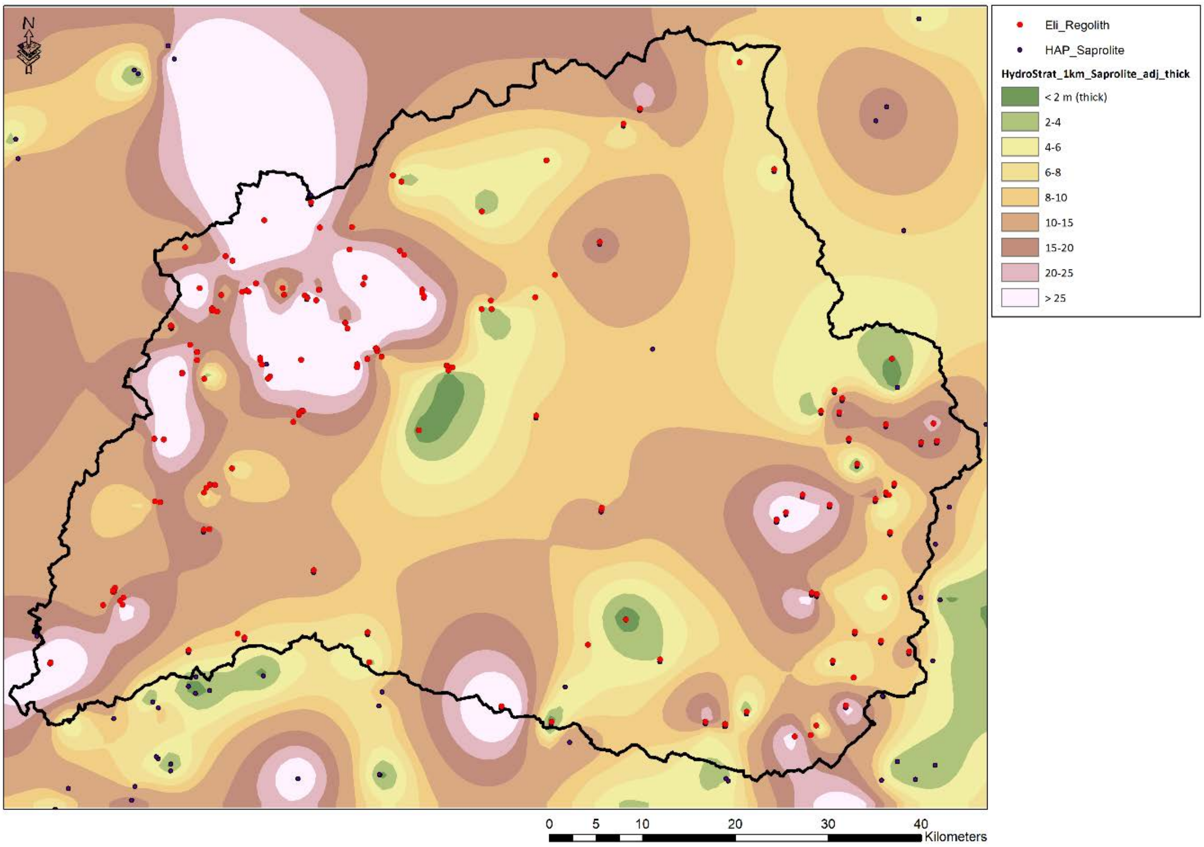

Figure 7 Calculated thickness of Saprolite

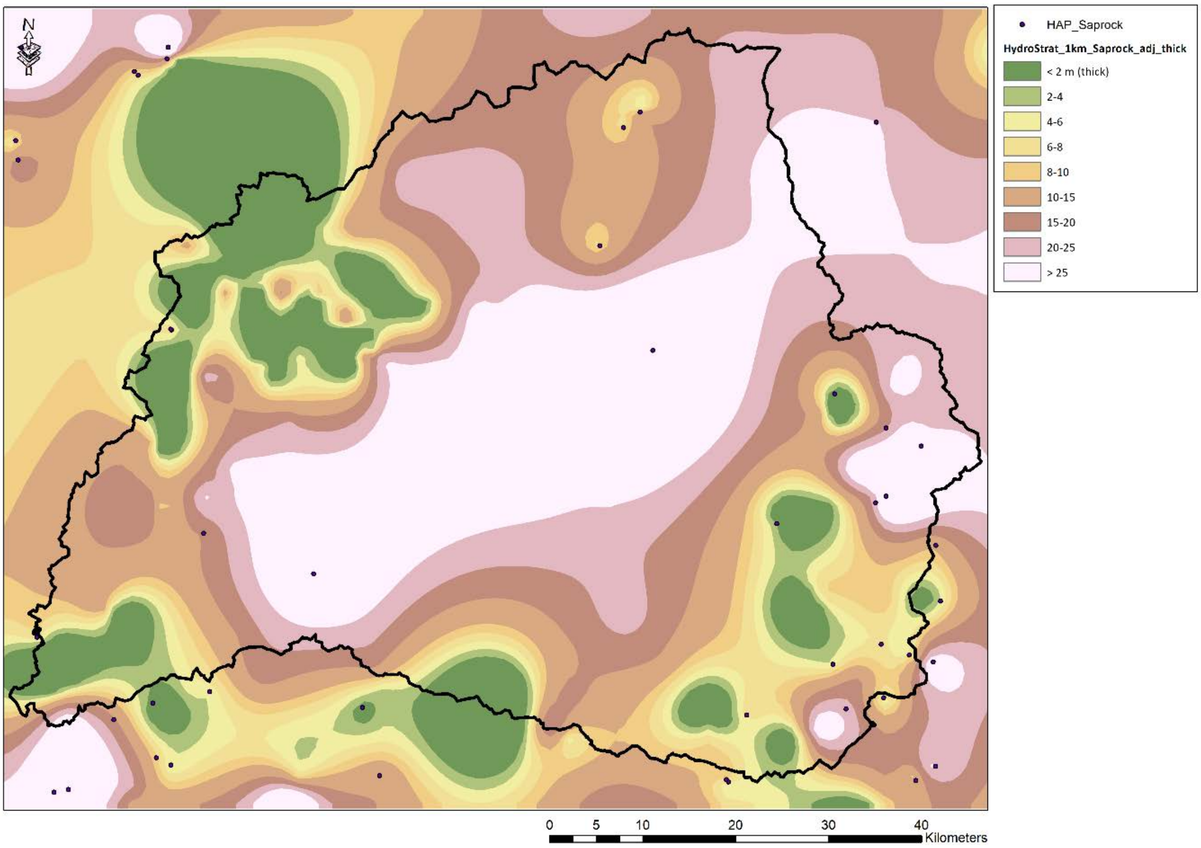

Figure 8 Calculated thickness of Saprock (stage 1)

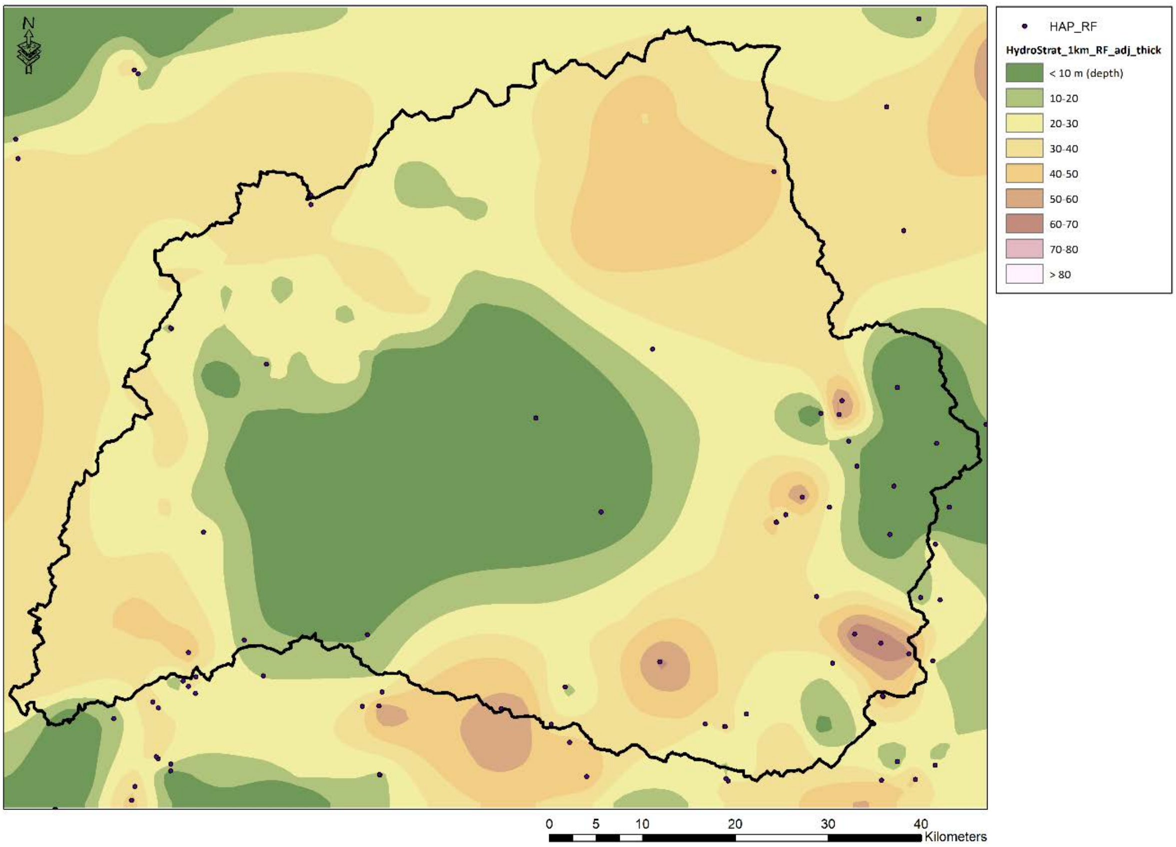

Figure 9 Calculated thickness of fractured bedrock (RF - sage 1)

For the second stage calculation of Saprock and RF, the individual layer thicknesses was extracted at well location and a composite Saprock thickness were calulated as the maximum of the grid value and the Saprock_depth minus Saprolite_depth, while the composite RF thickness was calculated as the maximum of the grid value and the RF_depth minus Saprock_depth. New estimates of Saprock (Figure 10) and RF thicknesses (Figure 11) were interpolated using the composite data and subsequently adjusted to have a minimum thickness of 0,2 meter.

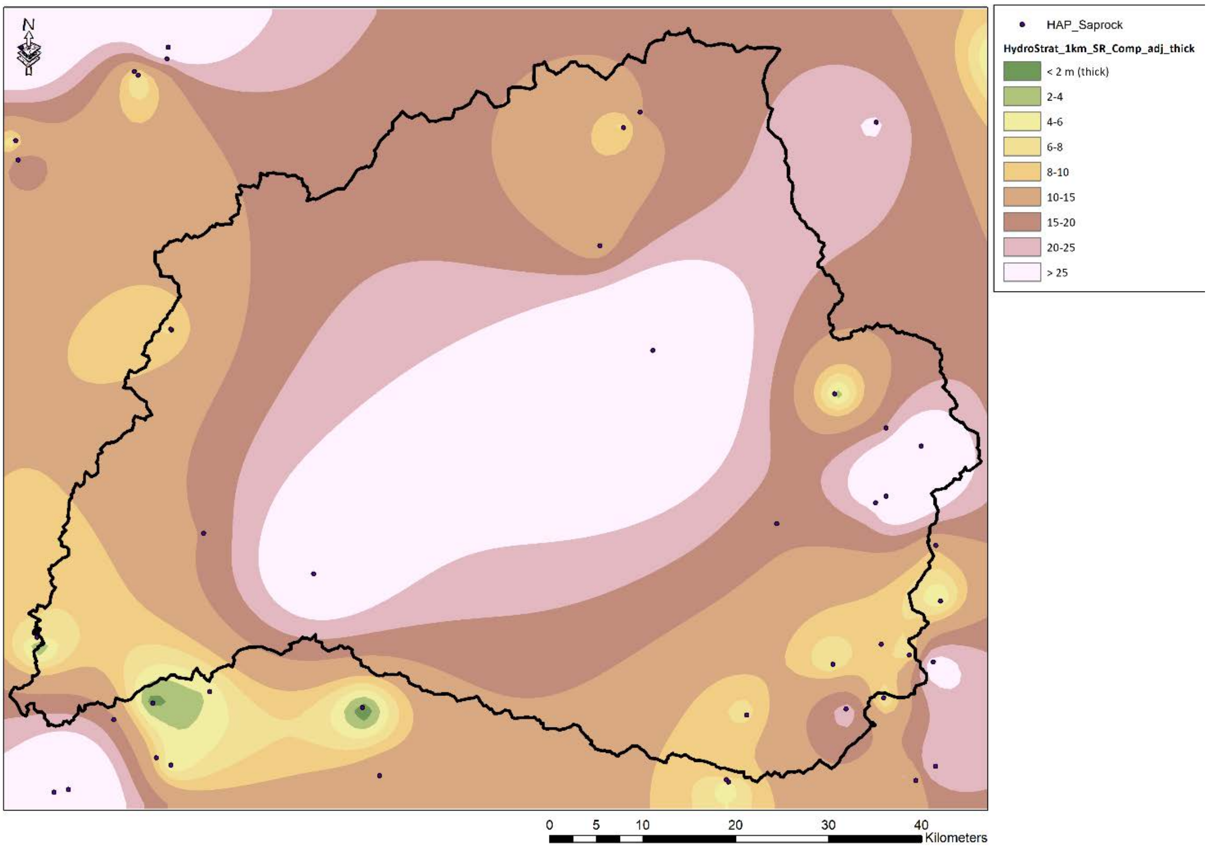

Figure 10 Adjusted composite thickness of Saprock (stage 2)

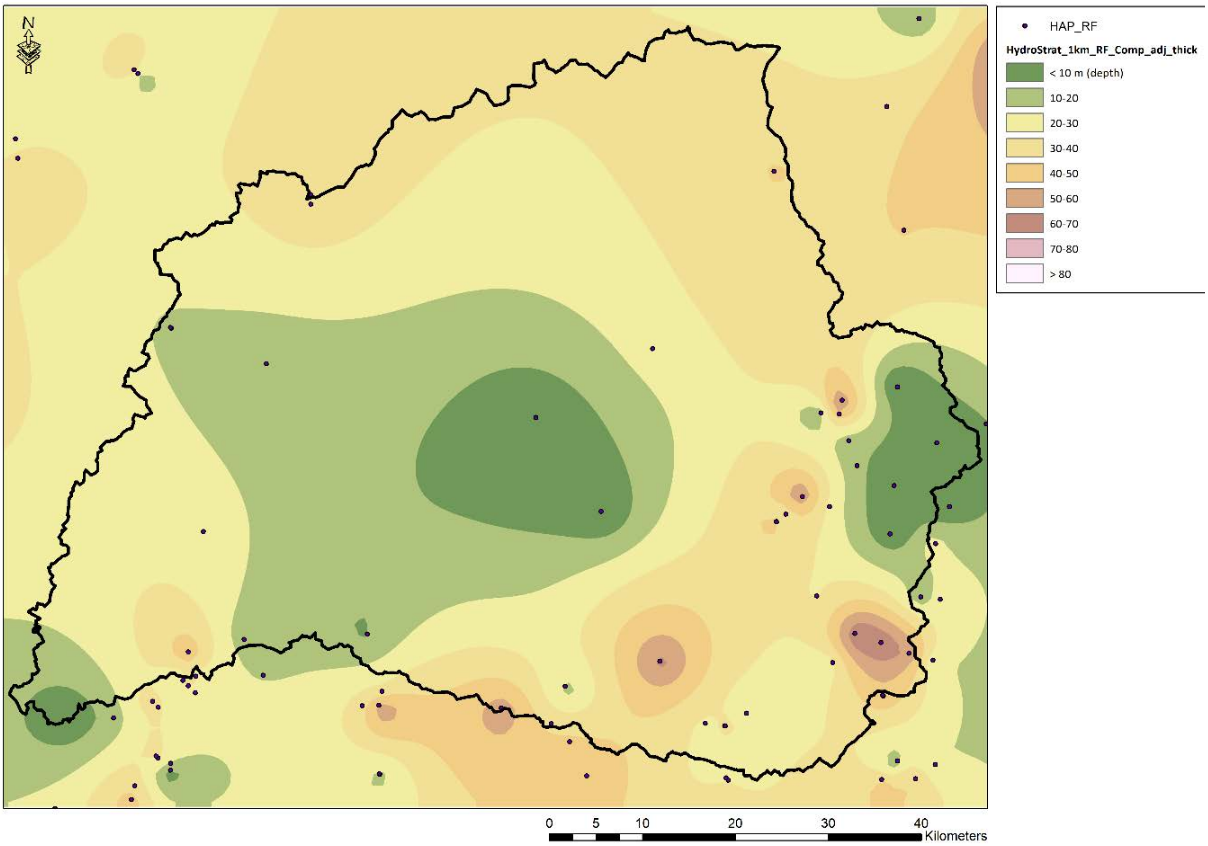

Figure 11 Adjusted composite thickness of Fractured Bedrock (RF - stage 2)

Topography

A 50x50m² topography was generated by merging of the Ghana50m topography (ghana50m_hts.tif) and the SRTM data in approximately 90m grid resolution (Jarvis A., H.I. Reuter, A. Nelson, E. Guevara, 2008, Hole-filled seamless SRTM data V4, International Centre for Tropical Agriculture (CIAT), available from http://srtm.csi.cgiar.org.), both found in the HAP database. The 50m topography was aggregated (mean values) to a topography grid in 1x1km² resolution (see Figure 12) matching the hydrological model resolution.

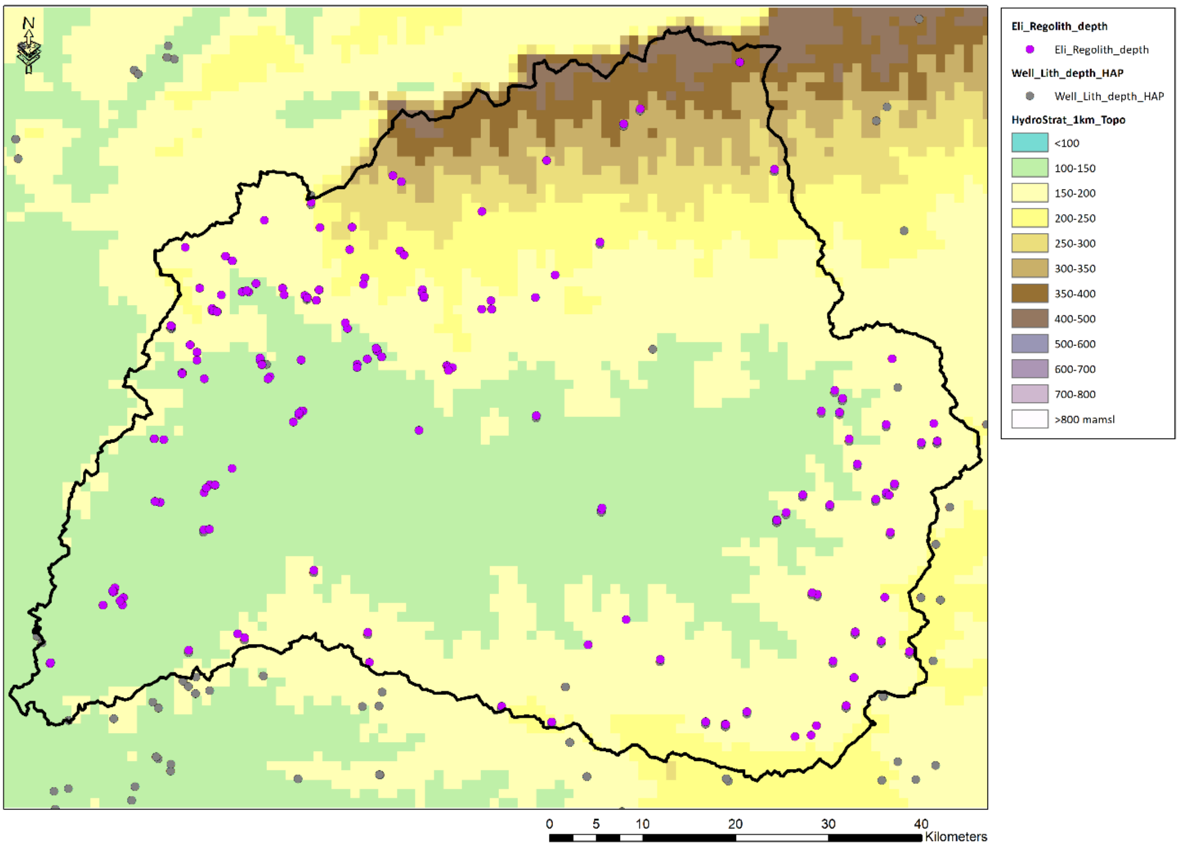

Figure 12 Topography in 1x1km² resolution

The topography in 1km resolution smoothens topographical variations especially in the higher regions of the Nasia basin. The standard deviation of 50m grid cells within 1km grid cells, Figure 13, shows small variation with a standard deviation of less than 2 meter near the main river compared a high variation with a standard deviation of more than 8 meters in the northern and southern part of the basin. A standard deviation of 8 meters roughly translates into that 20 out of 400 50m grids within the 1km grid has a topography that is larger than ± 16 meters different than the 1km grid value

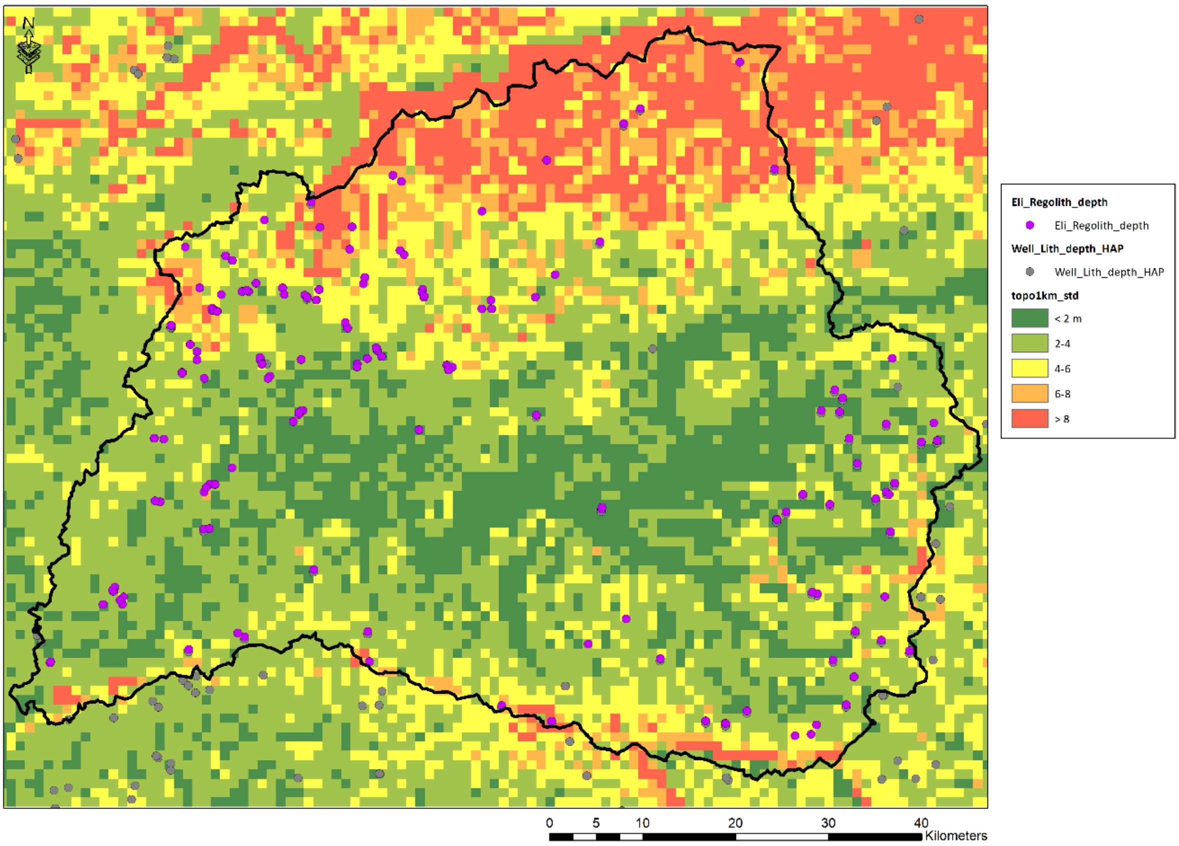

Figure 13 Standard deviation of the 50m grid cells per 1km grid cell

Hydrological model layers

The model layers (Figure 14 to Figure 17) are calculated directly from the hydrostratigraphic layer thicknesses, by subtracting thicknesses from topography (see Table 2 for naming and calculations). Data are exported to ascii grid in WGS 84 / UTM zone 30N projection for easy import to GMS and GeoScene3D using the same naming convention.

Table 2 Hydrological model layers

Grid name	Calculation method	Description
HydroModel_1km_RS_mamsl	*Topography* minus *RS thickness*	Bottom of Residual soil
HydroModel_1km_Saprolite_mamsl	*HydroModel_1km_RS_mamsl* minus *Saprolite thickness*	Bottom of Saprolite
HydroModel_1km_Saprock_mamsl	*HydroModel_1km_Saprolite_mamsl* minus *Adjusted composite Saprock thickness*	Bottom of Saprock
HydroModel_1km_RF_mamsl	*HydroModel_1km_Saprock_mamsl* minus *Adjusted composite fractured rock thickness*	Bottom of Fractured bedrock

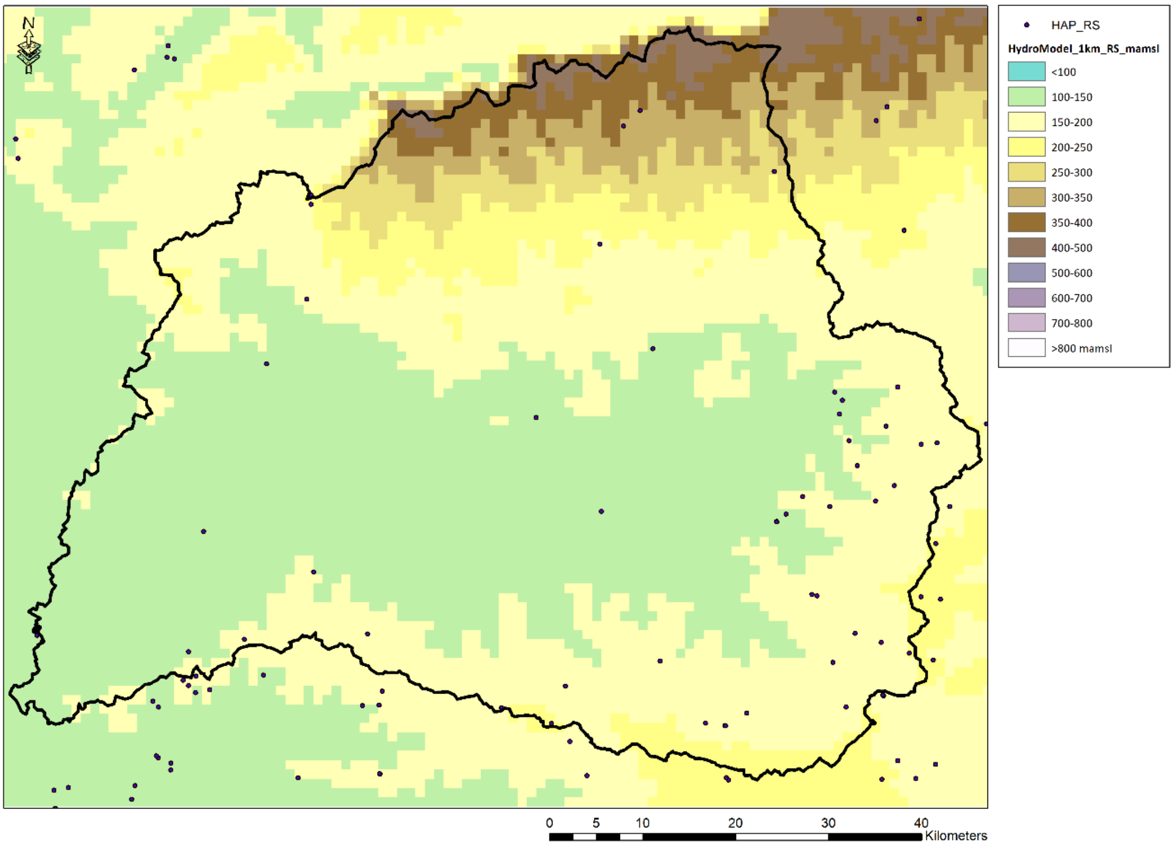

Figure 14 Hydrologcial model layer for bottom of Residual Soil

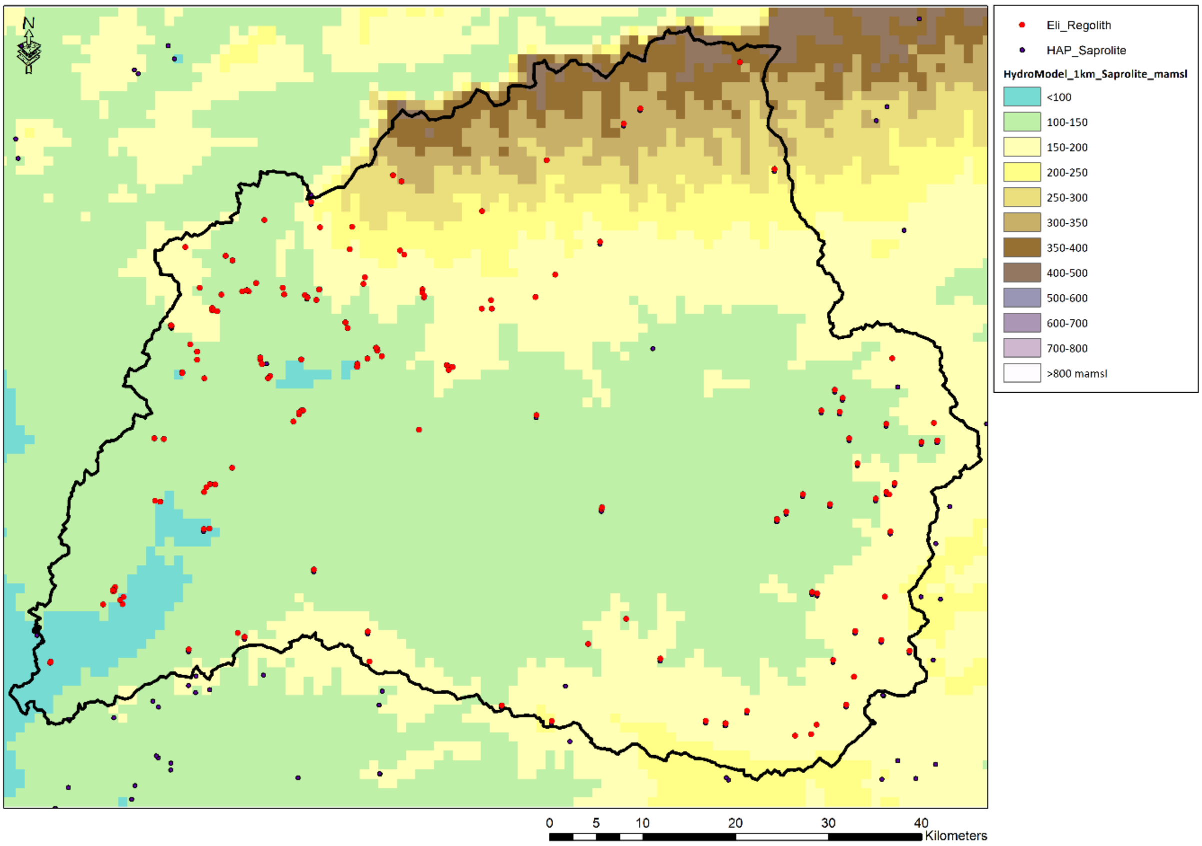

Figure 15 Hydrologcial model layer for bottom of Saprolite

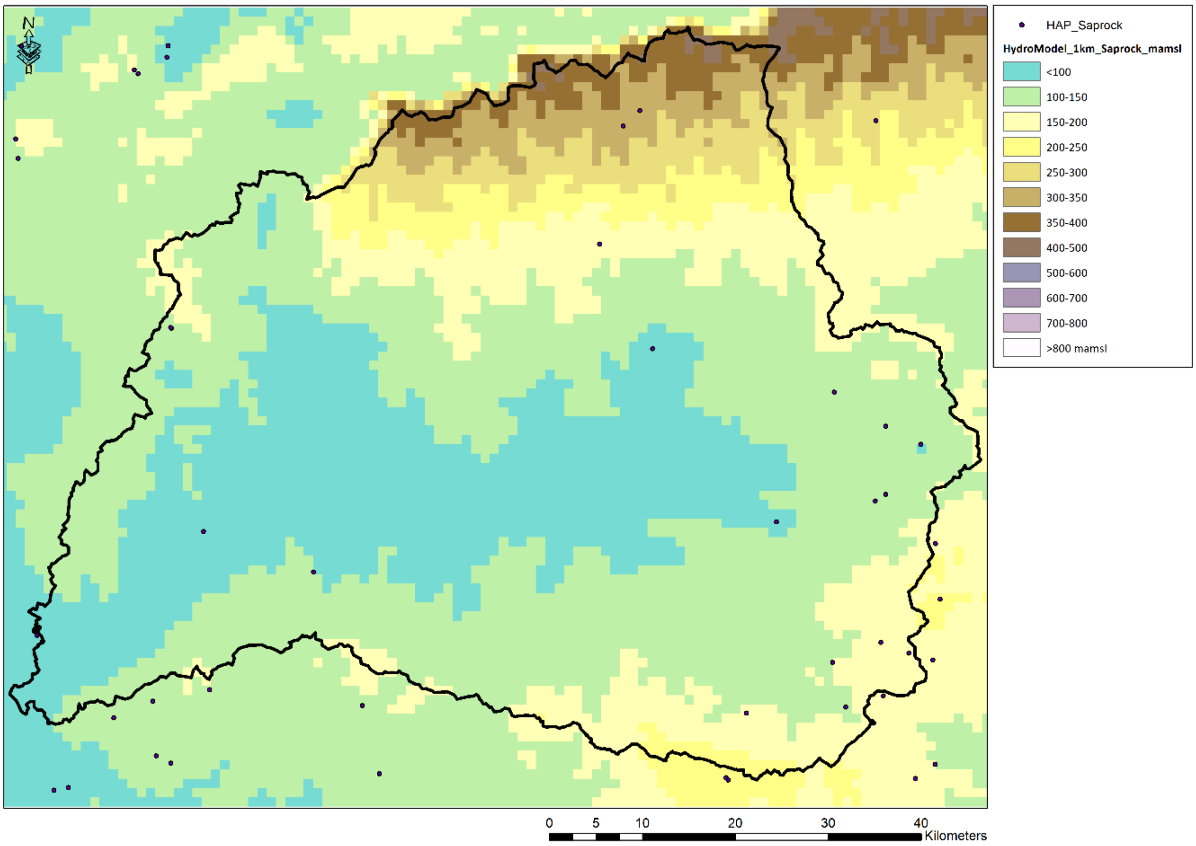

Figure 16 Hydrologcial model layer for bottom of Saprock

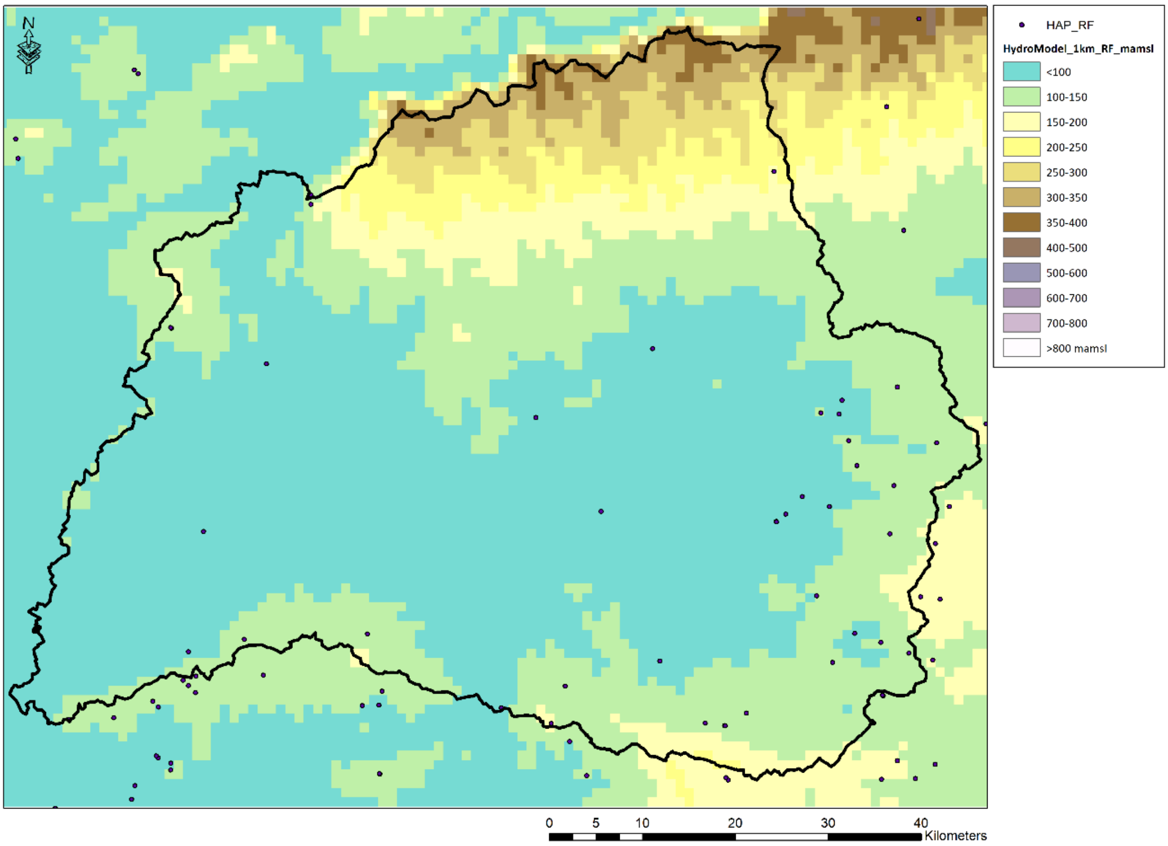

Figure 17 Hydrologcial model layer for bottom of Saprock

Groundwater elevation map

Given the large topographical variation in the Nasia river catchment and the relative small number of water level measurements interpolation of groundwater level (depth below surface) was preferred over direct interpolation of groundwater elevation. Water level data from the HAP database as well as data provided by Millicent was used for interpolation. Data from the HAP database came from the table "GroundWaterLevel". This table holds information on well id (hydro_id), measurement date and groundwater level in depth below surface, that where summarized into well id, no of measurements, min-, max-, standard deviation- and average groundwater level. Joining the summarized table to the well shape (well location file), thus producing a HAP well file with location and groundwater level data (a copy was exported to excel file: HAP_swl.xlsx). Project data collected from Nasia river catchment (Obed technical data report *in prep*) had several duplicates, thus an average was used for these, and data was lacking well_id making it difficult to correlate to HAP data, thus both dataset was used without further adjustments (e.g. duplicates removal) in the interpolation of groundwater level (see Figure 18).

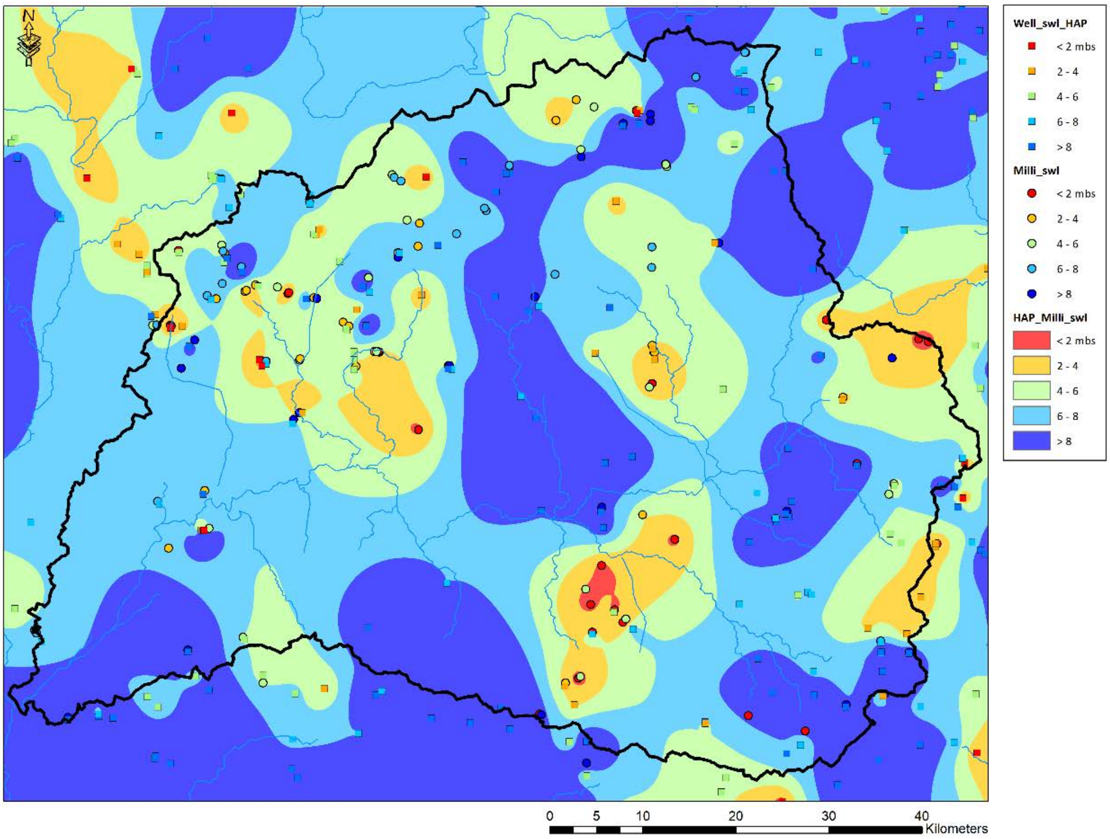

Figure 18 Interpolated groundwater level (meter below surface)

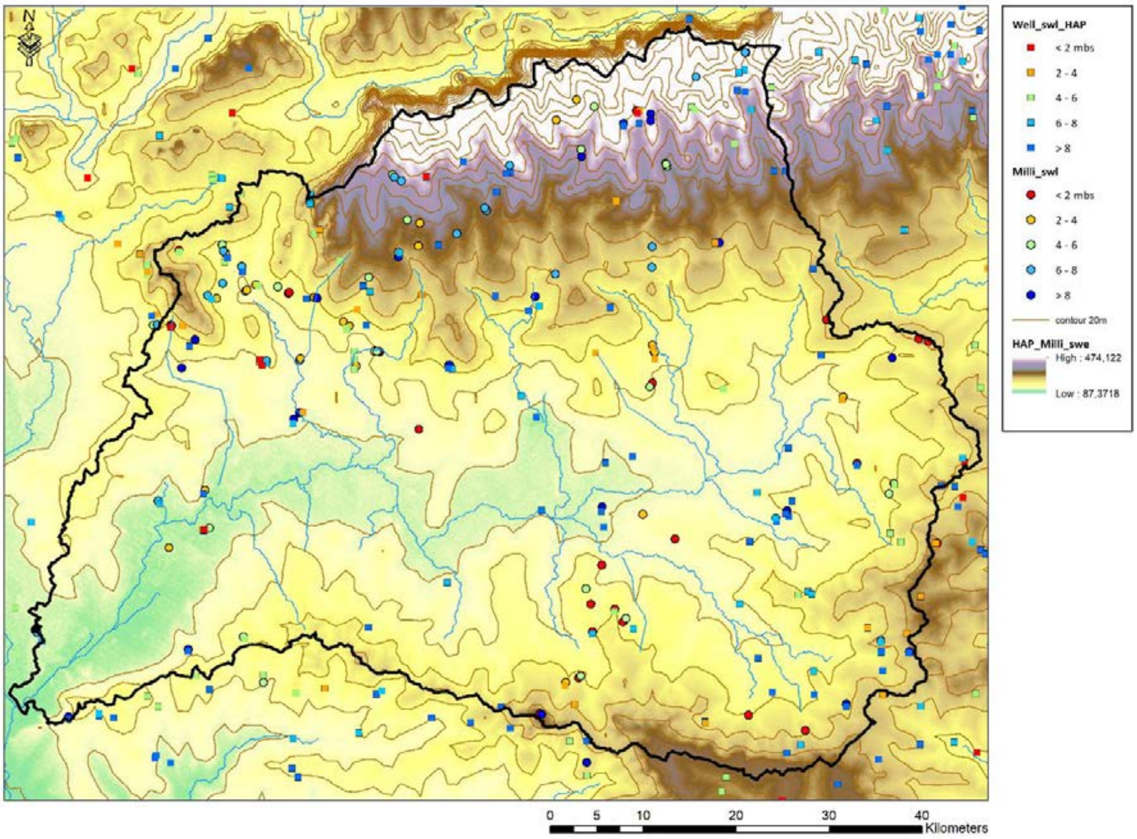

Figure 19 Estimated groundwater elevation (meter above mean sea level), derived 20m contours and groundwater depth data from project and HAP data

Groundwater elevation (Figure 19), in meter above mean sea level, was subsequently produced by simple subtraction between topography and the interpolated groundwater level. Contour lines was processed, based on the calculated groundwater elevation grid, and exported as polylines shapes for further analysis and boundary characterization.

Recharge map

Estimation of distributed recharge as input for the steady state hydrological model (GMS) was produced based on chloride mass balance (CMB) estimates from 73 different location (Millicent master study project/Obed technical data report) within the catchment and the estimate of precipitation distribution from the HAP database. Only the central ($Cl_{groundwater}/Cl_{rain}$) 95% part of the data was used for the interpolation.

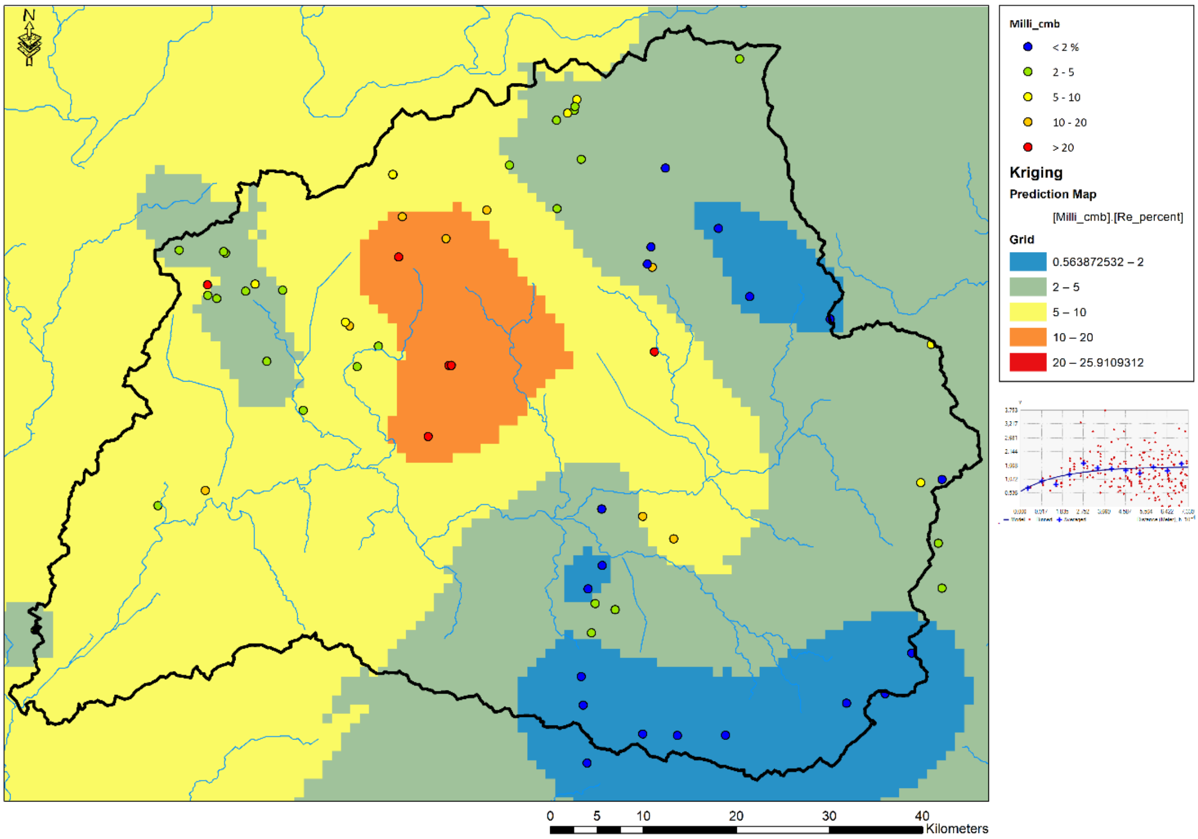

Figure 20 CMB map - estimated evapotranspiration in percentage of infiltration

Simple kriging, fitting data with an exponential model, was used to produce a CMB map for the Nasia Basin. The CMB map (Figure 20) is an estimate of 100% - thepercentage of infiltration that evapotranspirates. Through multiplication of the CMB map with the precipitation map from the HAP database (see Figure 21), a simple estimate of groundwater recharge is produced (see Figure 22). The method requires mean annual precipitation, and chloride concentration of the groundwater and rainwater. The CMB methods is considered as a reliable estimate of average groundwater recharge (not over- or underestimating recharge), with medium uncertainty ($R = P_{eff} * CL_{rain} / CL_{groundwater}$) (Walker et al. 2018). The method assumes that all chloride within groundwater originates from precipitation (alternative sources such as evaporates or pollution is not considered) and that evaporation of groundwater does not occur upgradient of groundwater sampling points.
The estimated groundwater recharge is made under the assumption that all precipitation is available for infiltration everywhere and that only the precipitation is available for infiltration (only direct recharge is estimated). However, since direct runoff was not incorporated in the estimate, the recharge may be slightly overestimated by use of this method. Similar the CMB

method neglects indirect recharge from areas affected by recharge from river flooding (where more water than precipitation is available for infiltration) and neglecting areas affected by precipitation induced surface runoff (in these areas the recharge may be significantly underestimated).

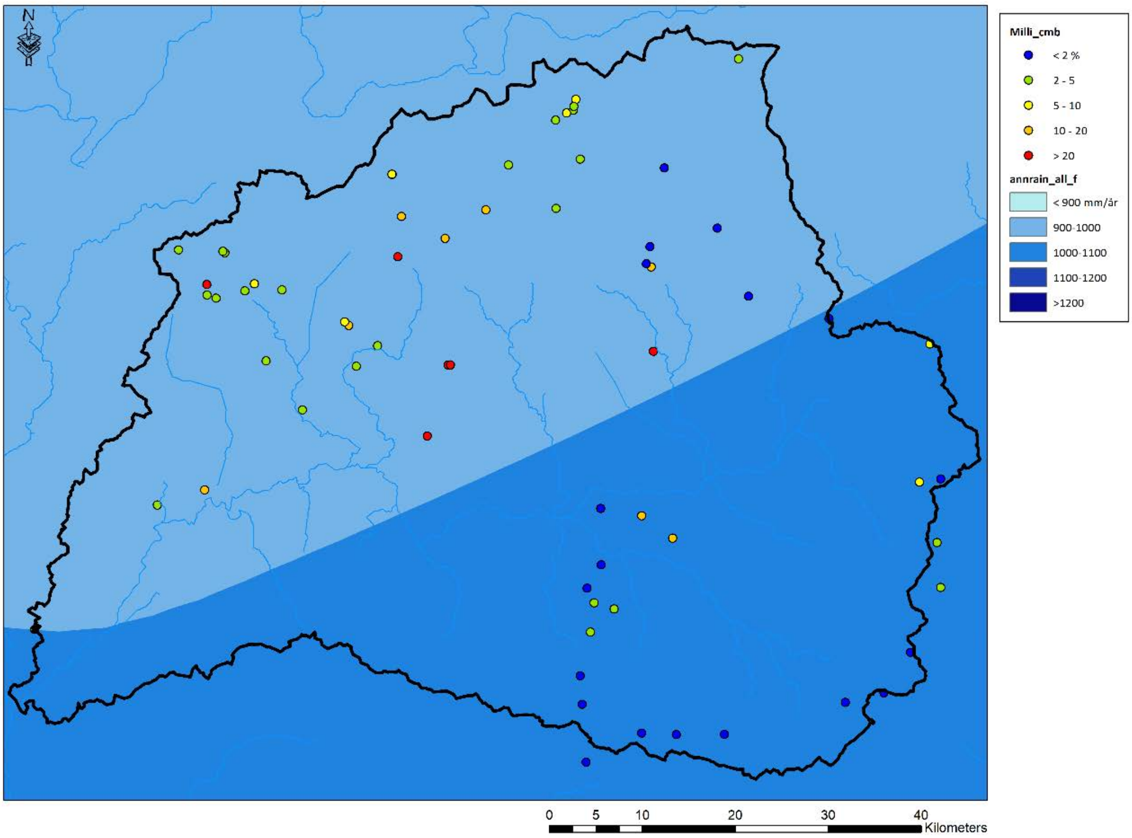

Figure 21 Precipitation map from the HAP report

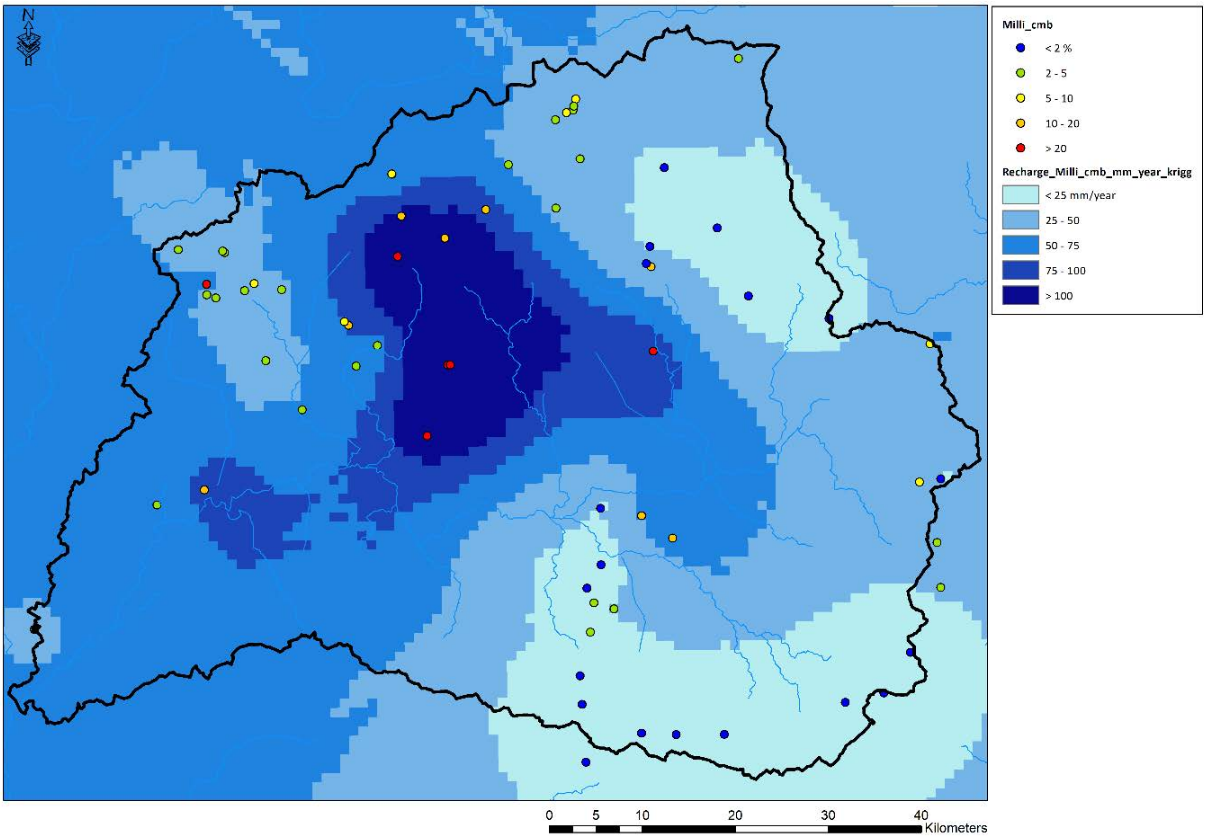

Figure 22 Recharge estimate from multiplication of the CMB map and the HAP precipitation map

References:

David Walker, Geoff Parkin, Petra Schmitter, John Gowing, Seifu A. Tilahun, Alemseged T. Haile, Abdu Y. Yimam 2018. Insights from a multi-method recharge estimation comparison study. Groundwater (12 June 2018). https://doi.org/10.1111/gwat.12801. https://onlinelibrary.wiley.com/doi/10.1111/gwat.12801