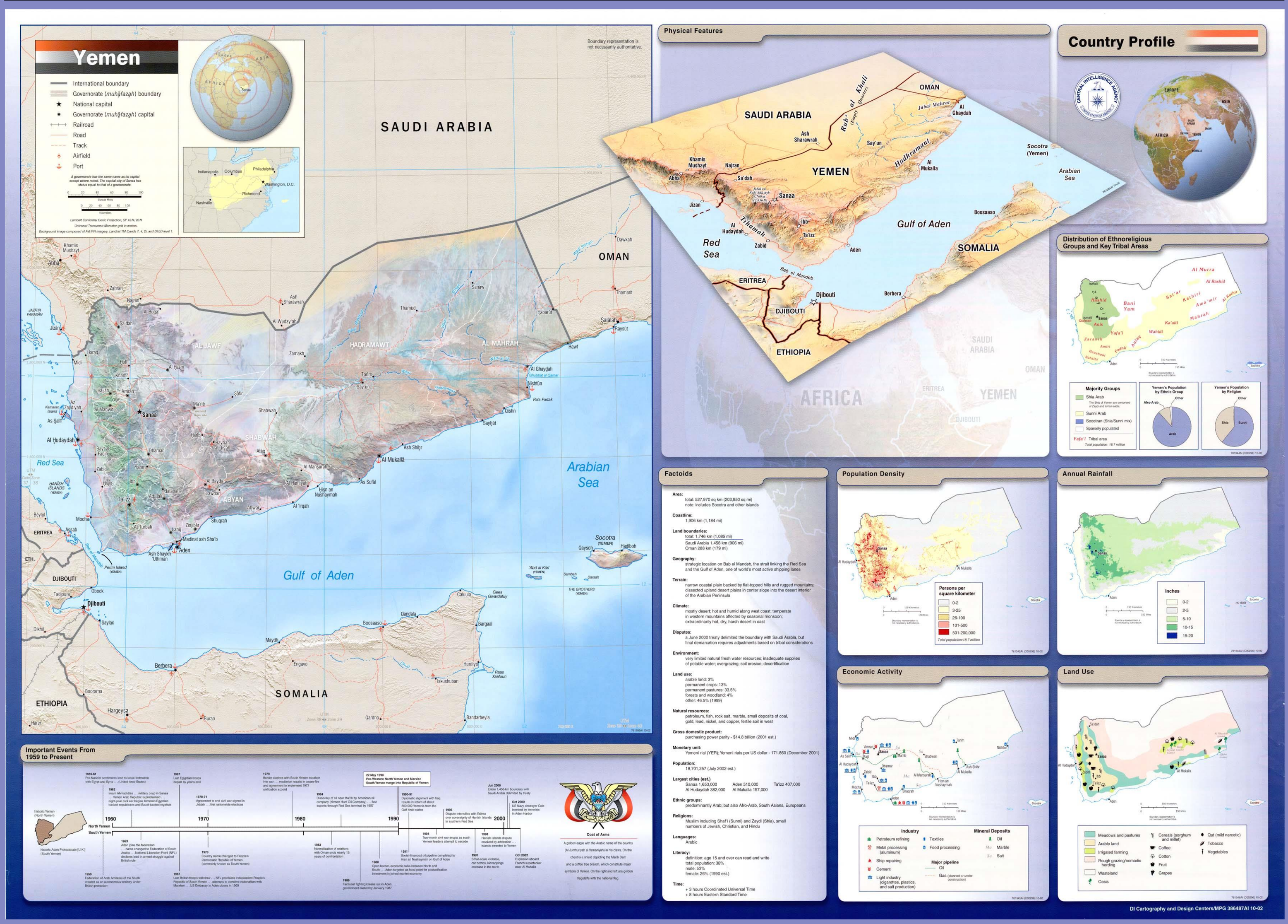
LITHOLOGIC CONSTRAINTS ON THE HYDROLOGICAL PARAMETERS OF REGIONAL AQUIFERS IN IBB PROVINCE, WEST-CENTRAL REGION OF YEMEN (MIDDLE EAST)

SHAMI, Malek[1], ALI, Zarine[1], ABDURABU, Wedad[2], KHANDAKER, Nazrul I.[1] and SCHLEIFER, Stanley[1],
(1)Geology Discipline, Earth and Physical Sciences, York College Of CUNY, 94-20, Guy R. Brewer Blvd, Jamaica, NY 11451,
(2)Department of Physics, Faculty of Science, Universiti Teknologi Malaysia, 81310 Skudai, Johore Bahru, Johore Bahru, 81310, Malaysia.

Abstract

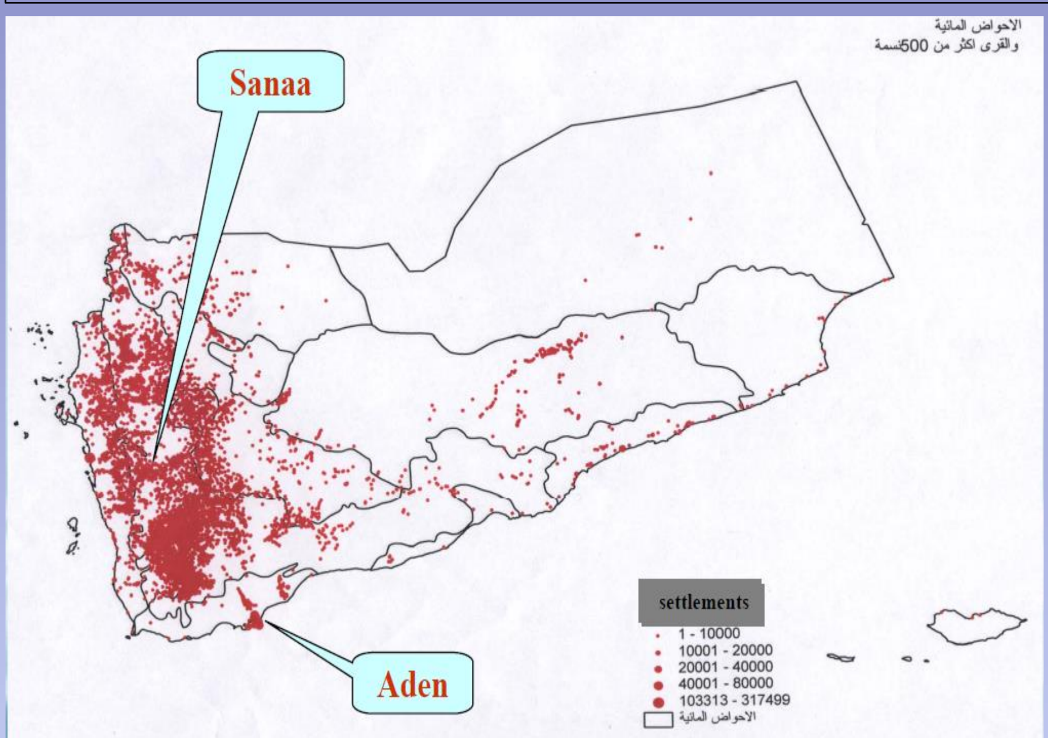
The lithology of Ibb Province Yemen (Middle East) consists of Precambrian gneissic bedrocks with post-tectonic intrusions of granite and granodiorite. The overall topography is dominated by extensive volcanic extrusions that randomly surround Ibb Province with minimal Mesozoic sedimentary outcrops. According to the Yemen Geological Survey and Mineral Resource Board (YGSMRB), the origin and age of such extrusive bodies that manifest on the surface as dikes, lava flows, and small (currently passive) cinder-cone volcanoes are of Cenozoic age associated with the rifting episode of the Arabian Peninsula and subsequent opening of the Red Sea. The overall aerial extension of the volcanic extrusions diminishes further east towards Hammam-Damt (Al'Dali Province) with a noticeable shift in magma composition from basaltic to rhyolitic. The regional aquifer, a vital source of drinking water, seems to possess similar hydrogeological properties across the Province. However, physical surveys of watersheds, stream patterns, passive pumping stations, and active freshwater wells suggest that unlike rhyolitic rocks, Basaltic rocks are non-vesicular type, dense and having no apparent hydraulic conductivity and in view of these unique lithological characteristics, do not promote groundwater recharge. Also considering extensional geomorphic control on the drainage pattern, it is possible that investigated drainages are fault or structure-controlled and provide a significant constraint on groundwater flow. Therefore, an assessment of such a geomorphological disadvantage was conducted by correlating with terrain geomorphology, bedrock composition, stream patterns, and hydrologic conductivity observed in water wells.

Country Profile Of The Study Site

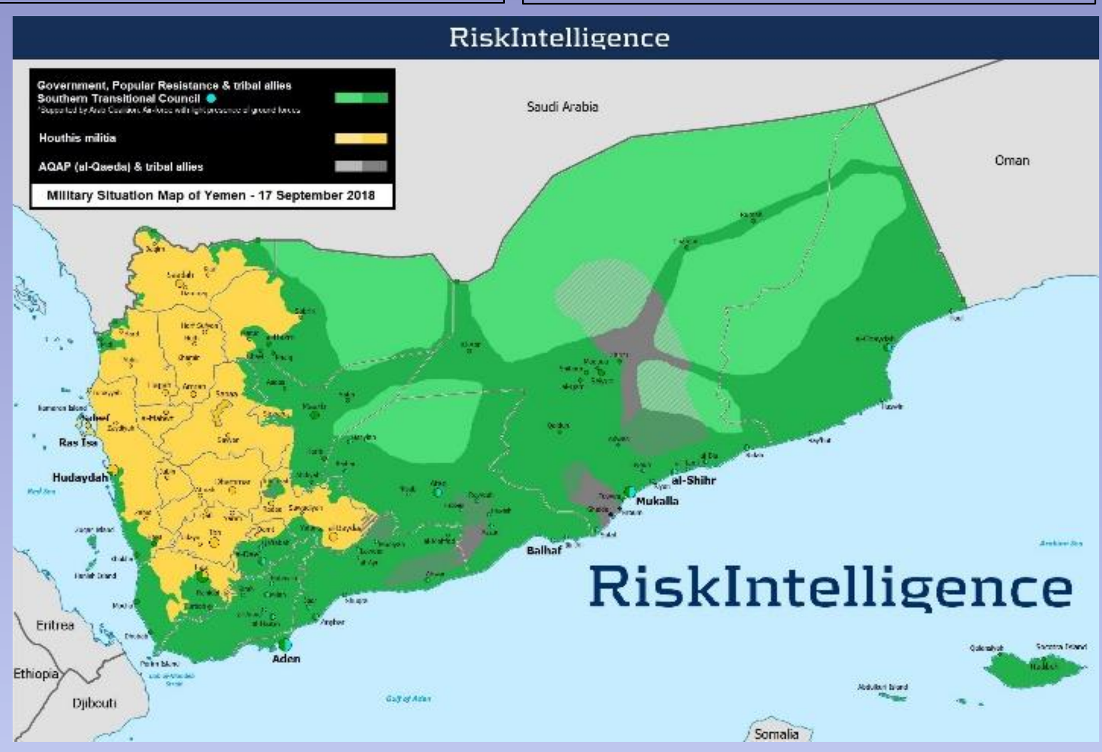


The Problem!

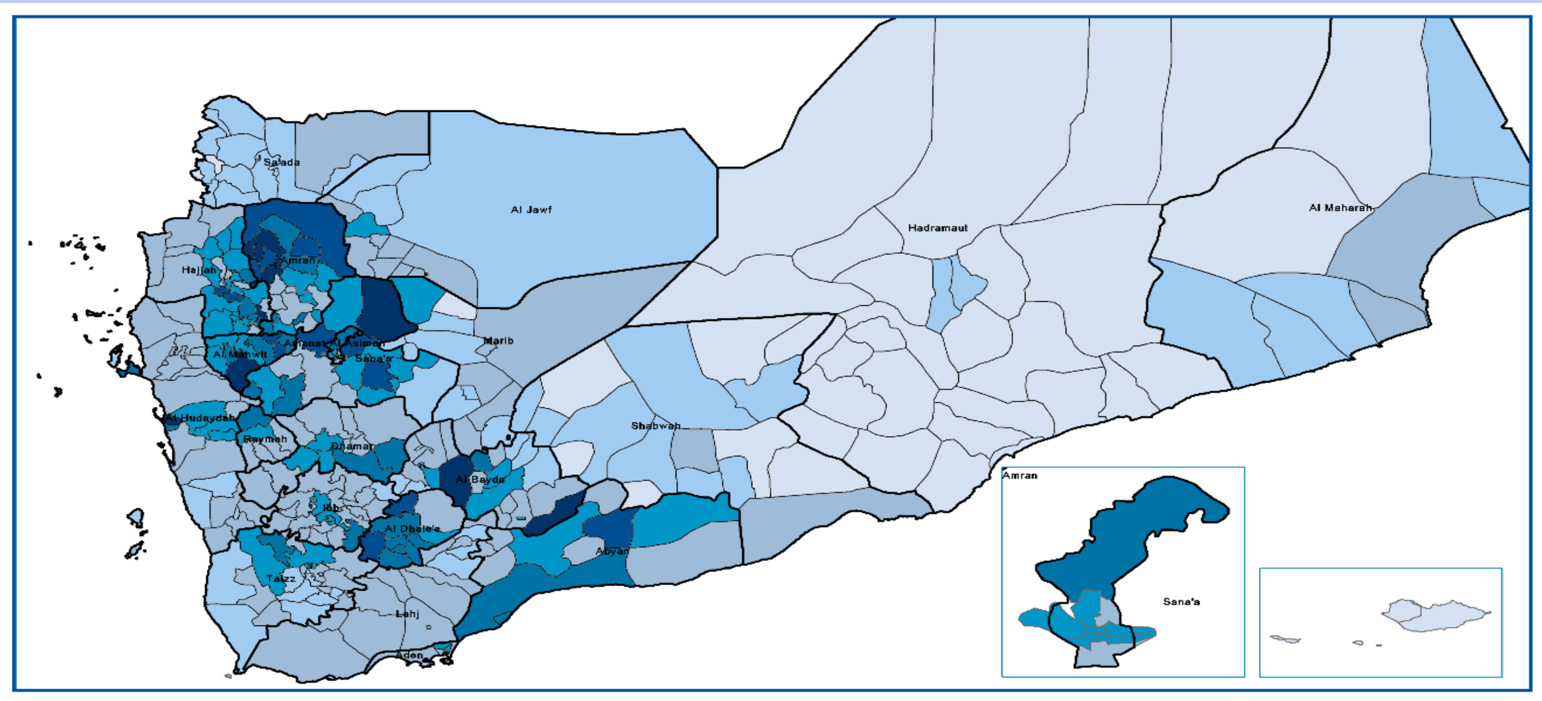
Divided into 22 geographical provinces (Governorates), Yemen has a total area of ~555,000 km^2. A 2006 demographic analysis estimated the population of Yemen is 26 Million, A ~100% increase since 1970. However, the major issue is the spatial distribution (Map.1). The biggest problem lies in the fact that nearly 80% of the population live on 20% of the land. Such odd demographic distribution is controlled by one main factor, access to clean drinking water. Current political, tribal, and military conflicts complicates this odd population distribution substantially. A Risk Intelligence Map (Map.2), published on September, 17, 2018, illustrates that the geopolitical conflict has a direct geographic correlation the highly populated northwest, west-central, and northern region. Such dispute complicate the access necessary fuel to operate groundwater pumping stations leaving nearly ~23 Million people without clean water.



Map.1 – Population Density of Yemen



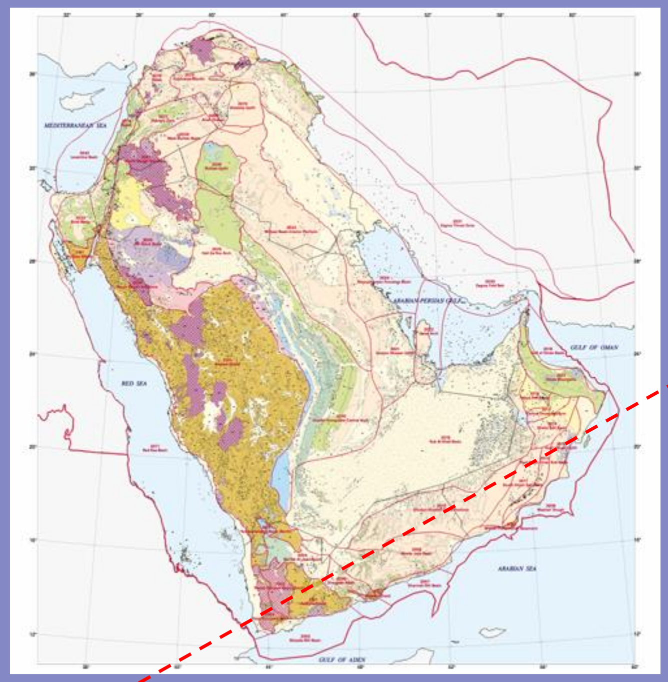
Map.2 – Risk Intelligence Situation Map of Yemen (UT)



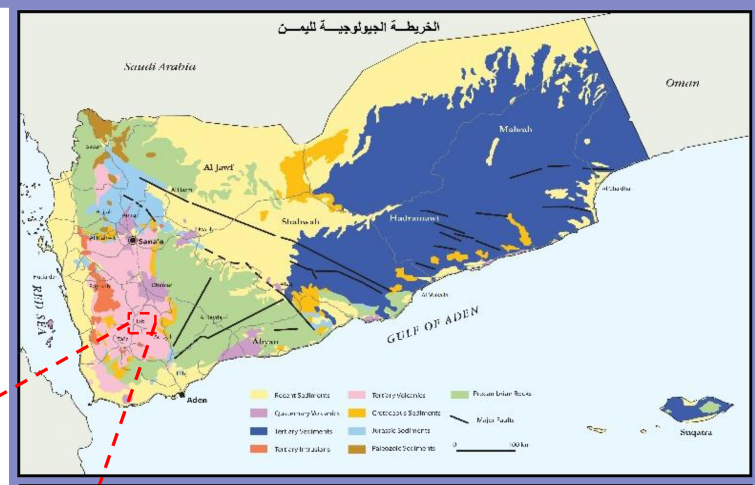
Map.11 – Geospatial distribution of Cholera Outbreak – attack rate / 10,000 (United Nations)

The World Health Organization (WHO) dedicated a website to monitor this overwhelming outbreak on weekly bases. In its July, 2018 report, "a total of 1.2 million cases of cholera were confirmed. Nearly 30% of the victims are children under 5 years" (Sharp, 2018). The United Nations Humans Rights Watch (HRW) confirms that a child dies every 10 minutes in Yemen while the fierce fighting, airstrikes, and lack of essential resources such as clean water continues to affect the population. Consequently, various epidemiological risk assessments pinpoint the lack of clean water access as the primary source of this colossal Cholera Outbreak. Map.11 – Geospatial distribution of Cholera Outbreak. (attack rate / 10,000)

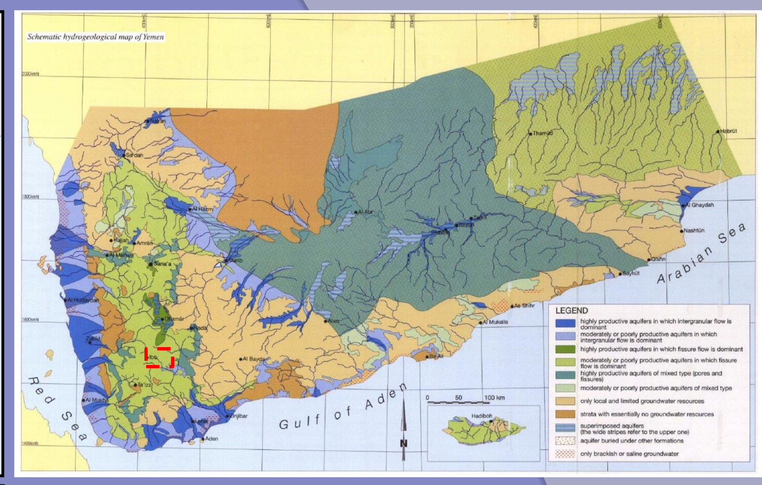
Geological Constraints



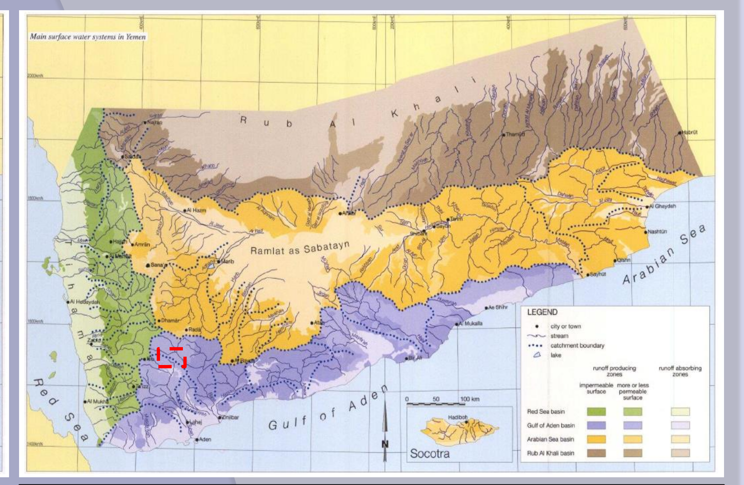
Map 3. Geology Of The Middle East



Map 4. Geology Of Yemen

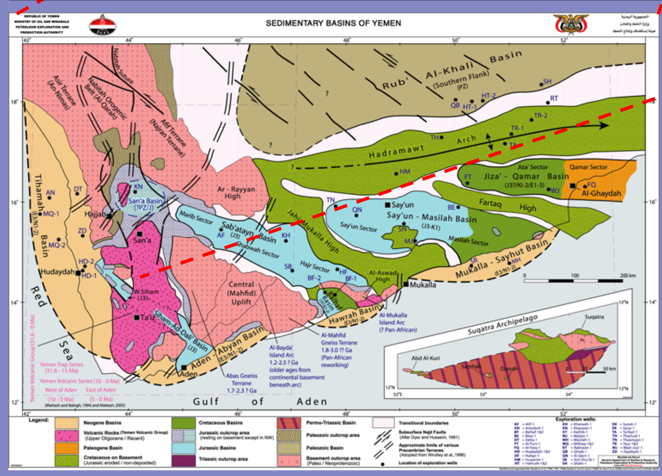


Map 5. Hydrological Map Of Yemen



Map 6. Regional Watersheds Of Yemen

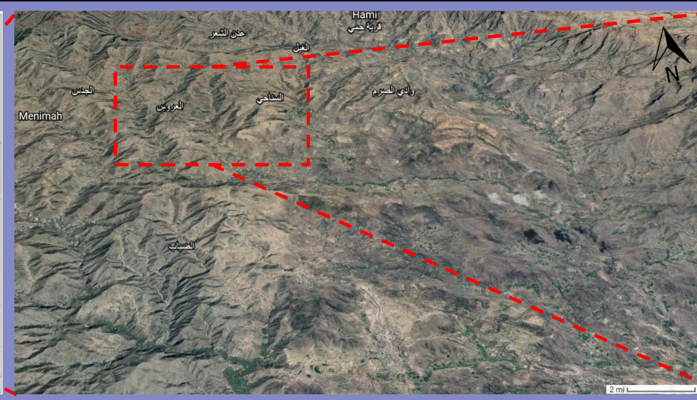
The general geologic map of Yemen (Map.4) illustrates that the west-central region is predominantly composted of Oligocene volcanic extrusions. However, a close-up on the lithology (Map.7) illustrates that weathering patterns exposed various underlying rocks in numerous erosional basins. The combination of such lithology coupled with the stream flow patterns of regional watersheds (Map.6) impose a geomorphological constraint on the recharge of regional aquifers (Map.5). The prevention of groundwater recharge into constantly pumped aquifers during the brief (~10 Inch Year^{-1}) rainfall facilitate a faster groundwater drawdown with an extremely slow recovery. Therefore, water sources of approximately 23 million people has become a scarce nonrenewable resource. Latest estimates by the Ministry of water project that at this rate of pumping, regional aquifers will be depleted by 2060.



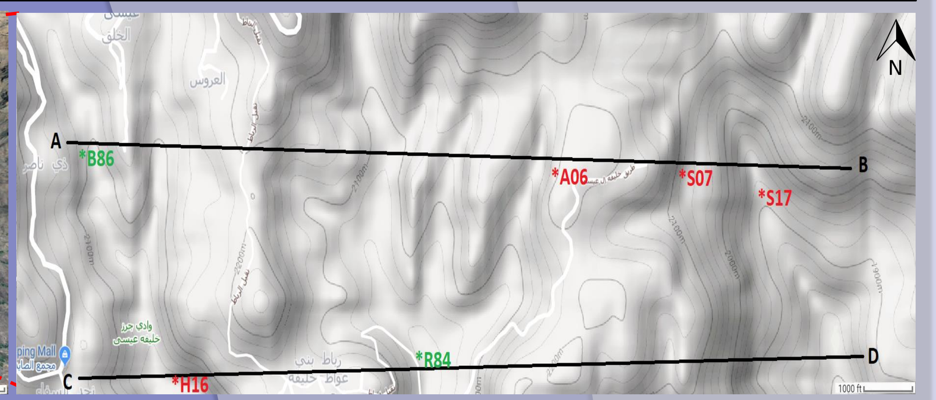
Map7. West-Central Sedimentary Basins

Study Site

Map 8. Study Site, Ibb Province



Map 9. Study Site, Ibb Province



Map 10. Topographic Map With Cross-Sections & Drilling Sites

Fig.1 Outcrops of Red (early Jurassic) sandstone and Oligocene Dikes

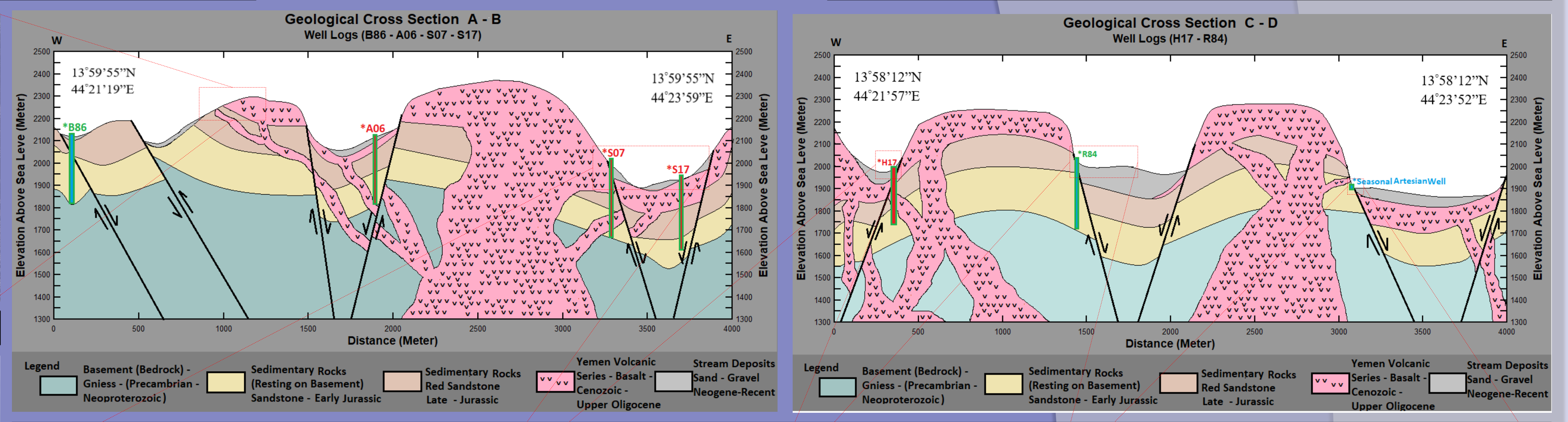
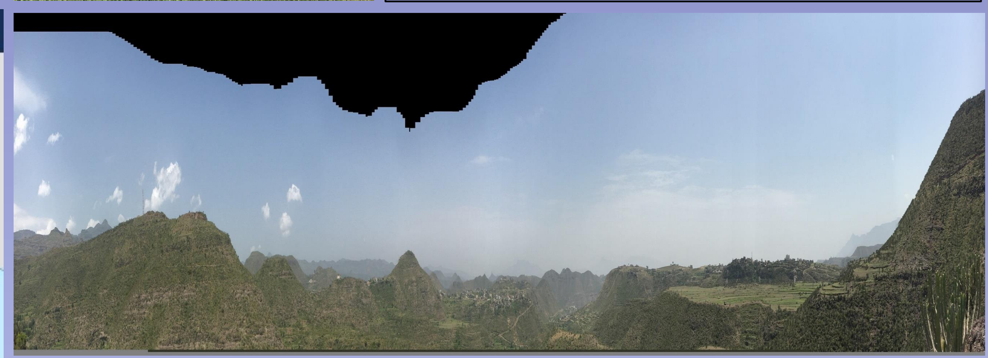


Diagram 1-2. Geological – Geomorphological Cross Sections with Well Logs

A correlation of terrain geomorphology, stream flow patterns, geologic mapping, and data from 6 active pumping wells reveals that post-tectonic extrusions of basalt impose a major disadvantage on groundwater recharge. The lack of hydrologic conductivity is caused by the impermeable fine basaltic which promotes surface runoff. However, locations with no basaltic constituent discourages surface runoff, promote aquifer recharge, and facilitate fast recovery of productive wells.

Fig.8 Aerial View of arid villages – Well *S07-*S17



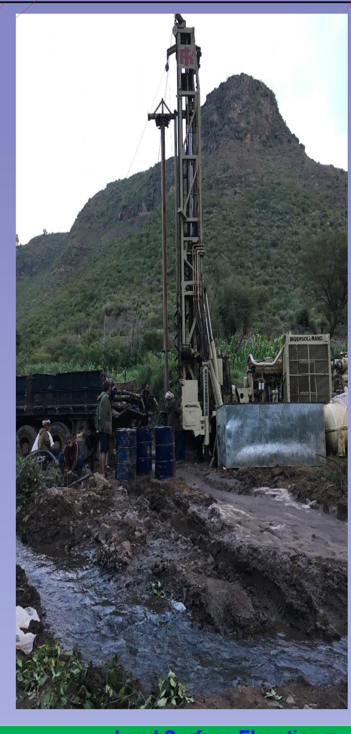


Fig.8 Valley of Well *R84

Fig.8 Aerial View of Artesian Well Location

Well logs (Table. 1) and geological surveys illustrate a uniform lithological distribution of Precambrian Gneissic basement rocks situated in a tectonically passive fault zone. Two, upper and lower, Jurassic Sandstones define the unconfined regional aquifer with respect to abundant Neogene stream deposits. Two cross sections (Diagrams. 1-2), A-B and C-D were crafted utilizing the data of wells logs and a massive scale geological mapping project. The remoteness of these locations posed a challenge in obtaining geological and hydrological data. The Geological Survey and Mineral Resource Board (YGSMRB) did very little work due to the nature of tribal landowners, sensitive privacy issues, and rugged mountainous terrains.
Results illustrate that there is a positive correlation between well log analyses coupled with geologic mapping to the poor or high productivity of ground water aquifers. Paleogene Basaltic extrusions (Figure. 1) are of fine grain that promote surface runoff and discourage groundwater recharge. Therefore, wells drilled directly in basaltic zones show very poor productivity while wells drilled within the same red sandstone aquifer (Figure. 1) away from basaltic volcanics show high productivity. Geomorphological surveys reveal that basaltic extrusions hinder groundwater recharge by promoting surface runoff in the form of small ephemeral streams. The absence of dense fine grain basalt promotes groundwater recharge through green luscious valleys filled with agricultural farming activities.

Depth (meter)			Lithologic Description	Top Elev.	Thickness (meter)
Well B86			**Land Surface Elevation =**	**2130**	**meter asl**
0	to	14	Sand	2130	14
14	to	27	Sand and gravel (dense)	2116	13
27	to	130	SandStone	2103	103
130	to	260	Red Sandstone (Aquifer)	2000	130
260	to		BedRock	1870	
Well H17			**Land Surface Elevation =**	**2000**	**meter asl**
0	to	50	Sand and gravel (dense)	2000	50
50	to	85	Basalt (Fine Grain)	1950	35
85	to	105	SandStone	1915	20
105	to	150	Basalt (Fine Grain)	1895	45
150	to	165	SandStone	1850	15
165	to	335	Red Sandstone (Aquifer)	1835	170
335	to		Bedrock	1665	
Well R84			**Land Surface Elevation =**	**2050**	**meter asl**
0	to	50	Sand and gravel (dense)	2050	50
50	to	80	SandStone	2000	30
80	to	350	Red Sandstone (Aquifer)	1970	270
350	to		BedRock	1700	
Well A06			**Land Surface Elevation =**	**2160**	**meter asl**
0	to	10	Sand	2160	10
10	to	25	Sand and gravel (dense)	2120	15
25	to	75	Basalt (Fine Grain)	2105	50
75	to	155	SandStone	2055	80
155	to	340	Red Sandstone (Aquifer)	1975	185
340			BedRock	1790	
Well S17			**Land Surface Elevation =**	**1960**	**meter asl**
0	to	140	Basalt (Fine Grain)	1960	140
140	to	310	Sandstone	1820	170
310	to	410	Red Sandstone (Aquifer)	1650	100
410			Bedrock	1550	
Well S07			**Land Surface Elevation =**	**2000**	**meter asl**
0	to	50	Sand and gravel (dense)	2000	50
50	to	150	Basalt (Fine Grain)	1950	100
150	to	230	SandStone	1850	80
230	to	245	Red Sandstone (Aquifer)	1770	15
245	to	335	Basalt (Fine Grain)	1755	90
335	to	355	Red Sandstone (Aquifer)	1665	20
355	to		Bedrock	1605	

Table. 1 –Well Logs of six active pumping wells

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