GROUND WATER FLOW IN COASTAL KARSTIC AQUIFER WITH PARTICULAR REFERENCE TO JABAL AL AKHDAR BENGHAZI PLAIN AREA

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Karst is a topography formed from the dissolution of soluble rocks such as limestone, dolomite, and gypsum. It is characterized by underground drainage systems with sinkholes and caves. The Karst water ground water hydraulics is strongly governed by the interaction between a highly conductive conduit network and a low conductive rock matrix under variable boundary condition. The ground water flow system in the Karstic aquifer can be classified as Diffuse Flow Karst System, Conduit Flow Karst System and Mixed Flow Karst System. Karst System provide a ground water flow pattern much different from sandy aquifers. The Benghazi Plain Aquifer is confined between Mediterranean Sea and the first escarpment of Jabaal Al Akhder basin in the eastern part of coastal Libya. The flow conditions in the Benghazi plain aquifer are extremely complex. Not only the medium is highly anisotropic and heterogeneous but also, the nature of flow varies from laminar to turbulent. These conditions pose serious limitation on the use of standard techniques of estimating the hydraulic parameters like transmissibility, storage coefficient etc. In the present paper aquifer characteristics have been evaluated both by standard methods and also, by using data on water level fluctuation due to barometric pressure and ocean tides. In the Benghazi Plain transmissibility varies from very low (i.e. areas with no yield) to very high (i.e. karstic channels). The present study reveals that the aquifer in the Benghazi plain area is neither completely intergranular type it is completely dominated by the presence of karstic channels. Both these phenomena (i.e. intergranular nature and preferential channels) have their roles to play in shaping the flow regime of the aquifer. The flow condition is essentially laminar in the intergranular part and it becomes turbulent in the karstic channels.

KEY WORDS: Karst System, Aquifer, Transmissibility, Storage Coefficient.

INTRODUCTION:

Water is an essential resource for mankind. The largest source of fresh water is available from underground water. Increased demands for fresh water have stimulated large scale development of underground water. India being a monsoon fed country often we face drought condition due to extended dry period and thus excessive withdrawal of underground water becomes a necessity and this may invite environmental and quality related problem. Efficient management of ground water needs a comprehensive study on occurrence and movement of underground water. The occurrence of ground water is intensively related to the geological strata features in both vertical and aerial extent. The geological zones related to ground water must be identified and their structures and characteristics must be qualified and quantified in terms of water holding and water yielding capabilities. The ground water holding strata can be classified as aquifer, aquitard, aquiclude and aquifuge depending on occurrence and movement of water. The source of ground water is ultimately from rainwater which is the primary source of overall hydrologic cycle. This paper particularly describes the flow of ground water in karstic aquifer formed by solution cavities. Normally Karstic aquifers are very complicated with high anisotropy and heterogeneity. Examples of Karstic aquifers can be drawn from South Kashmir and coastal aquifers in Libya and Oman.

KARSTIC AQUIFER:

Karst is a topography formed from the dissolution of soluble rocks such as limestone, dolomite and gypsum. It is characterized by underground drainage systems with sinkholes and caves. However, in regions where the dissolved bedrock is covered (perhaps by debris) or confined by one or more superimposed non-soluble rock strata, distinctive karst features may occur only at subsurface levels and can be totally missing above ground. These karst features form aquifers .However these aquifers are highly anisotropic and heterogeneous.

Karst aquifers are very productive and constitute important groundwater resource of approximately a quarter of the global population. Karst aquifers are very unique compared to uniformly porous (Darcian) aquifers, since the process of carbonate rock dissolution (karstification) generates a distinct heterogeneity and anisotropy. observable in the characteristic duality of discharge patterns (Bakalowicz 2005).Karst aquifers can be conceptualized by three levels of porosity (1) the primary porosity of the rock matrix (2) The secondary porosity of fractures, cracks, bedding planes , joints and faults.(3)The third porosity resulting from the dissolution of the bedrock along the fracture or faults. Most of the conspicuous landscapes on earth are formed by karstification, where sinkholes (dolines), swallow holes, poles and karren are present on the surface (exokarst) and a discrete network of conduits and caves are developed subterraneanly (endokarst). The upper few meters of the rock layers are usually more affected by karstification and weathering (epikarst) and often reveal a higher degree in permeability as the aquifer below. Since permeability decreases with depth and fine sediments partly clog the vertical infiltration paths, in many karst environments this zone is regarded as a transition zone where infiltrating water is often stored temporally (perched aquifer), sometimes for several years. In the weathered zone, water is drained laterally towards discrete vertical fissures and shafts, from where it percolates towards the phreatic zone . However, in arid regions, the weathered zone may be developed to a much lesser extent than in humid regions since carbonate dissolution depends on the presence of water (H_2O) and dissolved carbon-dioxide (CO_2)(Bakalowicz 2005; van Beynen 2011). Therefore, karst features are mostly independent from the geographic and climatic setting, but may vary in their degree of karstification and morphological shape (Kresic et al 2013). Leyland etal(2008) presented a vulnerability mapping in Karst Terrains.

Karst aquifers are especially difficult to exploit, manage, and protect because of the extreme variability of their hydraulic properties which are almost impossible to determine at a local scale. Moreover, their functioning may be influenced by non-linearities and threshold effects. Considering long-term aquifer exploitation, karst system complexity does not allow for easy modelling. However, because karst aquifers may offer great storage capacity and high local hydraulic conductivity, high flow rates can be pumped from single sites, allowing for effective management of an aquifer. (Van Beynen, 2011).

Naidoo (2014) in his investigation on hydrogeological characterisation of the Karst aquifer in the city of Tshwane municipal area supplying water to Pretoria has presented some details on the process of karstification. The process of Karstification is controlled by many factors including the quantity of precipitation, the partial pressure of CO_2 and the hydraulic gradient from recharge area to the discharge area. Drogue (1974) hypothesised that the pattern of karst network follows the pre-existing fracture pattern in the dolomite rock. However, most of the karst hydrogeologists (Leyland et al 2008) believe that the pattern of the karst network is different from the pattern of pre-existing fractures. The "Karst Process" are thought to select any geological discontinuity such as a joint or fracture and enlarge it until it is hydraulically connected from surface to discharge point. At the end of the karstification process the conduit network that is left is highly permeable & highly heterogeneous and can conduct large quantities of water as the conduits in these networks are generally ba number of meters wide and can be a few kilometres long. This is because Karst aquifers have a double or triple porosity which is composed of. voids, fractures and the intergranular pores in the rock matrix (this portion may be very low in unweathered dolomite but may be higher in the weathered dolomite).The pores in the rock matrix generally form the storage of aquifer and the conduits and fractures act as drains of the aquifer.

GROUND WATER MOVEMENT IN AN AQUIFER:

The extraction of ground water from aquifer needs construction of a structure like dug well, bore-well , infiltration gallery , or tube-well. The yield from a water extraction structure depends on the storage and flow characteristics of water in the aquifer. These characteristics are defined below:

1. Potentiometric surface or piezometric surface :An imaginary surface or hypothetical surface of the piezometric pressure or hydraulic head throughout all or part of a confined or semi confined aquifer analogous to water table of an unconfined aquifer.
2. Transmissivity : It measures the amount of water that can be transmitted horizontally by a full saturated thickness of aquifer. It is a product of average hydraulic conductivity (m/day) and thickness of the aquifer. Unit of Transmissivity is m^2/Day. Hydraulic Conductivity is a measure of ease with which water flows through aquifer and is defined as the amount of flow per unit cross section under the influence of a unit gradient.
3. Storativity or Storage Coefficient: The volume of water that a permeable aquifer unit will absorb or expel from storage per unit surface area of aquifer per unit change in hydraulic head.
4. Specific Capacity: It is a measure of both effectiveness of a well and of aquifer characteristics (Transmissivity & Storativity) . It is defined as the ratio of the pumping rate and the drawdown (lowering of water table/piezometric level).

Groundwater flow in the subsurface is driven by differences in energy /head. Water flows from high energy/high head part to low energy /low head zone. The total head of flowing ground water is governed by Bernoulli's Equation and comprises Gravitational Potential energy (datum Head) plus Pressure Head plus Velocity Head. The movement of a fluid (ground water) through a porous media is a subject by itself and has been presented in detail by Scheidegger(1974), P.Ya . Polubarinova Kochina & Roger de-weist(1962),Glover(Engineering Monograph 31).The ground water flow can be either laminar if Reynolds number is less than 2200 or turbulent if the Reynolds number is higher than 2200. For laminar flow the flow velocity is directly proportional to hydraulic gradient. This type of ground water flow is governed by Darcy's law. In unconsolidated rocks or semi-consolidated rocks the Reynolds number is mostly below 2200 and the flow is laminar and follows Darcy's Law.

$q = Q/A = - K*(dh/dl)$ (1) Where,

q = Specific Discharge, Q = Discharge, A = Cross Sectional area.

dh/dl = Hydraulic Gradient, K = Hydraulic Conductivity.

Todd (1959/1964) has presented a detailed discussion on Ground Water Movement following Darcy's Law.

Witherspoon et al (1980) have examined the validity of cubic law for fluid flow in a deformable rock structure. The cubic law states that transmissivity is proportional to cube of an aperture in fracture. Cubic Law can be expressed as

Q/Дh = C*(2b) ^3

Where,

Q = Flow Rate

Дh =Difference in Hydraulic Head

C = Constant that depends on the flow geometry and fluid properties.

2b = Fracture Aperture.

Turbulent ground water flow can occur in many aquifers through relatively large interconnected porosity. Turbulent flow is characterized by streamlines flow in random complex patterns (eddies) because of viscous forces of the water being overcome by shear stresses within the water.

Turbulence in ground water flow has been examined by Smith and Nelson (1964).The problem of turbulent flow was analysed by using pipes of circular section as flow channels of underground rocks. Pipe diam. 0.25 mm to 150 mm have been used . Critical velocities have been calculated from Reynolds's equation. The result show that the groundwater flow is turbulent in the larger pipes.

Quin Jiazhong et al (2005) has made an experimental study of turbulent unconfined ground water flow in a single fracture. The average flow velocity was approximated by an experimental empirical exponential function of the hydraulic gradient and the power index of the experimental function was close to 0.5.

The effect of turbulent groundwater flow on hydraulic heads and parameter sensitivities was examined for the Biscayne aquifer in southern Florida using the Conduit Flow Process (CFP) for MODFLOW-2005. (Shoemaker, W.B 2009).

Medici, G, L et al (2019) studied implications of groundwater flow velocities in a fractured carbonate aquifer for transport of contaminants. For the case study aquifer the work flow predicts hydraulic apertures ranging from 0.10 to 0.54 mm. The ground water flow velocities for these conditions range from 13 to 242 m/day. Hydraulic Conductivity on the other hand range 0.30 to 2.85 m/day.

The turbulent flow of ground water through fractures in hard rock or karstic limestone aquifer can be simulated to an interconnected pipe flow Thus this can be compared to the equation for pipe flow presented below:

V = 0.85*C*R^0.633*S^0.54 (2).

Here the power of slope factor s is significant.

Varalakshmi,V et al(2014), generated a model of the hard rock aquifer comprising granites, basalts and small amount of laterites in Osmansagar and Himayathsagar catchments with the help of MODFLOW software and studied recharge and discharge to evaluate the effect on water table.

In hard rock or karst aquifer the permeability (ease with which water flows in an aquifer) may be associated with three types of system porosity which are presented in table 1 below (Ghasemizadeh,Et Al, 2012)

Permeability	Dimension	Travel Time	Flow Mechanism	Distribution
MATRIX	Micrometre to millimetre	Long	Laminar Flow Darcy Law	Continuous
FRACTURE	10 micrometre to 10 millimetre	Intermediate	Cube Law Laminar/Transition Flow	Localized
CONDUIT	Higher than 10 millimetre	Short	Open Channel or Pipe Flow	Localized.

GROUND WATER MODELLING IN KARST AQUIFER:

The flow conditions in hard rock and semi-consolidated rocks have been discussed in the last section. The karst aquifer can be considered as a special type of hard rock aquifer where large dimensioned solution cavities exist in the form of conduits and provide huge storage of water and gets recharged through minor solution cavities and allows the stored water to flow through cracks and fissures. Thus a portion of karst aquifer allows movement of ground water following Darcy condition and a major portion allows movement following Conduit condition.

In order to take care of the huge heterogeneity in ground water aquifer particularly in karst aquifer statistical approach has been applied increasingly to groundwater flow problems. This development has been motivated by the recognition of the fact that properties of aquifer vary in an irregular manner in space.

The first step to modelling needs examination of scaling heterogeneity. Here two concepts need examination. Hewett (1986) suggested modelling of geological formations with the tools of self-similarity and fractal dimensionality. This approach assumes that there is no disparity between scales rather a continuum of successive new scales of heterogeneity is found as the size of the observation domain increases all such scales of variability being self-similar. Pardo-Iguzquiza Et Al (2019) and Badino (2001) have examined the Fractal Behaviour of Karst massif. Many features of a karst massif has a fractal distribution and can be modelled using a fractal geometry. A fractal is a geometric object that is similar to itself on all scales. The hydrogeological parameters of the karst massif such as hydraulic conductivity and karst spring hydrograph may exhibit fractal behaviour.

The second approach to modelling assumes disparity of scales.(Dagan ,1986,Neuman & Federico,2003). Ground water aquifers being heterogeneous, exhibit both discrete and continuous spatial variations on a multiplicity of scales. It is therefore natural to expect that hydro-geologic variables would do likewise. Neuman et al (2003) have presented evidence that hydro-geologic variables exhibit isotropic and directional dependencies on scales of measurement (data support), observation (extent of phenomena such as a dispersing plume), sampling window (domain of investigation), spatial correlation (structural coherence), and spatial resolution (descriptive detail). Dagan (1986) has presented three distinct scales namely Laboratory Scale, Local Scale and Regional scale to model hydrogeological conditions. Flow domains were characterized by the length **s**cale **L** of their spatial extent and three such scales of a fundamental nature were introduced: the laboratory, the local, and the regional scale. Heterogeneity was characterized by the spatial correlation scale I of the property of interest, the three scales corresponding to the above ones being the pore scale, hydraulic conductivity, and transmissivity integral scales. The medium properties and related flow variables were considered as random stationary space functions. An additional scale D the measurement or computational scale, characterizing the size of the measurement device of a flow variable or the element over which the variable is averaged for computational purposes. In both cases, the interest resides in the space average of the flow variable over a volume or area of length scale D. For regional studies L designates the size of catchment, I designates the average length of fissures and D the size of drawdown cone during a pumping test. Where, $I \leq D \leq L$. However, Williams, Roy E has criticised this approach by Dagan (1986) and have observed that the scale classification proposed by Dr Dagan is framed very loosely and may not be suitable for setting up large scale experimental investigation.

Teutsch ((1989) and Teutsch & Sauter (1991) have presented use of models for study of Swabian Alb Limestone Karst aquifer in Southern Germany. In this study Teutch & Sauter (1991) have utilised the Scale Hierarchy suggested by Haldorsen (1986) using the three scales L, I &D suggested by Dagan (1986).They have analysed the hydrogeological data using Single and Double Continuum flow and transport models.The double continuum model presented in the paper by Teutsch(1989) is based on the well-known USGS MODFLOW packages. However, the structure of the programme was different because of two binstead of one continuum and the cross flow calculation. Teutsch& Sauter (1991) have reviewed the following framework of different types of models for karstic aquifer:

1. Single Continuum Porous Equivalent.: SCPE
2. Double Continuum Porous Equivalent DCPE
3. Single Continuum Porous Equivalent and Discrete Singular Fracture Set: SCPE + DSFS
4. Discrete Singular Fracture Set : DSFS
5. Discrete Multiple Fracture Set : DMFS

The above models may be applicable starting from deterministic model in no 1 gradually traversing to stochastic simulation in no 5.

The data for the model by Tatsch & Sauter (1989) were collected from

A.Hydraulic Phenomena :
1. Large Scale Hydraulic (Pumping) Test.
2. Spring Flow Hydrographs
3. Ground Water Level Measurement
4. Small Scale Hydraulic Tests (Pumping Tests).
B. Transport Phenomena :
1. Aerial Source Tracer Tests
2. Point Source Tracer Test.

Based on the above data the models were framed in line with the following Systems

1. Conduit System
2. Diffuse System
3. Mixed Diffusion Conduit System

Ghasemizadeh et al (2012) in a paper on groundwater flow and transport modelling of karst aquifer with particular reference to the North Coast Limestone Aquifer System of Puerto Rico have presented a table on differently named distributed modelling approaches for Karst Aquifers. These are presented in Table 2 below:

Table 2 :

Modelling Approach	Other Names	Type
Equivalent Porous Medium Approach (EPM)	Single Continuum Porous Equivalent Approach (SCPE) Heterogeneous Continuum Approach Distributed Parameter Approach Smeared Conduit Approach Single Continuum Approach	Distributed Deterministic
Double Porosity Model	Double Continuum Approach (DC) Double Continuum Porous Equivalent Approach (DCPE)	Distributed
Discrete Fracture Network Approach (DFN)	Parallel Plate Model : 1) Discrete Singular Fracture Set Approach (DSFS) 2) Discrete Multiple Fracture Set Approach (DFMS)	Distributed
Discrete Channel Network Approach(DCN)	Discrete Conduit Network Approach(DCN)	Distributed
Hybrid Model (HM)	Combined Discrete Continuum Approach (CDC) Combined Single Continuum – Discrete Fracture Set Approach (SCPE-DSFS).	Distributed
Hydrograph Chemograph Analysis	Single Event Methods	Lumped Deterministic
Linear Storage Model	Rainfall Discharge Models Time Series Analysis Box Models	Lumped Stochastic
Self-Computing Methods	Computationally Intelligence Methods	Lumped Deterministic Stochastic

PUMP TESTING IN KARSTIC AQUIFER:

Pump test provides a very useful tool for the evaluation of aquifer characteristics. Through pump test one can obtain important hydraulic parameters in the region surrounding the pumping well. The two important hydraulic parameters namely transmissivity and storage coefficient can be calculated from unsteady state aquifer performance test data in darcian aquifer where groundwater flow is laminar .Most of the equations used to analyse pump test data have been generated for sedimentary rock aquifers considering the aquifer to be unconfined ot confined (Todd,1959,Brown ,1953, Krusman & DeRidder,1970).

Marechal Et Al (2004) have used hydraulic tests at different scales to characterize fracture network properties in the weathered fractured layer of a hard rock aquifer. The hydrodynamic properties of the weathered fractured layer of a hard rock pilot watershed in a granitic terrain was characterized using hydraulic tests at different scales. The interpretation of numerous slug tests led to characterize the statistical distribution of local permeabilities in the wells. A method to estimate aquifer thickness and hydraulic conductivity has been developed by Marechal Et Al (2010) by conducting multiple pumping tests. The method requires short duration pumping cycles on an unconfined aquifer with significant seasonal water-table fluctuations. The interpretation of several pumping tests under various initial conditions provides information on the change in hydrodynamic parameters in relation to the initial water-table level. The transmissivity linearly increases compared with the initial water level, suggesting homogeneous distribution of hydraulic conductivity with depth. The hydraulic conductivity is estimated from the slope of this linear relationship. This test can only be applicable in poorly developed karst system termed as Diffuse Flow Karst System (DFKS).

Thrailkill (1988) developed a specific approach based on drawdown interval analysis to establish aquifer flow characteristics of conduit flow karst system (CFKS) covering maturely karstified aquifer or free flow aquifer characterized by turbulent flow or free surface flow in solution cavities. In shallow conduit flow (SCF) carbonate aquifers, the nature of the void space and groundwater flow differs from that of granular aquifers in that the voids are solution conduits, often of large size, and flow is generally non-Darcy. These and other characteristics of SCF aquifers preclude the application of pumping test analysis methods based on the diffusion equation. The drawdown interval analysis (DIA) method, which is consistent with a conceptual model of the SCF aquifer, provides estimates of aquifer parameters using both direct calculation and simulation approaches. Application of the DIA method to two wells yielded parameter values which are consistent with the hydro-geologic setting of the wells.

In between the two extreme types of carbonate karst aquifers namely Diffuse Flow Karst System and Conduit Flow Karst System there exist a Mixed Flow Karst System (MFKS).This MFKS can be conceptualized as dual or triple flow system comprising localized and often turbulent flow in solution cavities or conduits and Darcian flow or diffuse flow in fractures or in porous rock. Marechal et al (2008) worked on a long duration pump test in the conduit of a mixed flow karst system and developed a double continuum model consisting of two reservoirs one a karst conduit and the other covering surrounding carbonate rocks. The flow exchange between Karst conduit and surrounding carbonate fractured rock was modelled by using superposition principle and the hypothesis of Darcian flow in the matrix component and infinite hydraulic conductivity in the karst conduit. In this MFKS it was observed that the matrix hydrodynamic parameters (Hydraulic Conductivity and Storativity) had a greater influence on the drawdown than the storage capacity of the conduit.

Dausse et al (2019) carried out a multiscale investigation on the Lez Karst Aquifer a Mediterranean karst system located in Southern France. This study illustrated a strong variability of hydraulic properties as well as a clear flow ranking. The transmissivity of the Lez aquifer obtained by several methods provide the following values for transmissivity in different zones :

1) Below 10^-7 sqm/sec for the matrix zone
2) 10^-7 to 10^-3 sqm/sec for fracture network
3) Higher than 10^-3 sqm/sec for karstic zone.

KARST AQUIFER IN INDIA:

Dar et al (2014) made a study of the carbonate aquifers and karst hydrogeology of South Kashmir India. About 3 % of India's total land surface is occupied by carbonate rocks which are mostly karstified and constitute a significant source of groundwater. The groundwater drawn from these aquifers matches the water demand of about 35 million people living in 106 districts of the country and also the water needs of livestock, irrigation and industry.

Shah (2017) presented a detailed hydrogeological characteristics in three mesoscale mountainous catchments (Liddar, Kuthar & Bringi) of Western Himalayas to understand the karstification history and to estimate the residence time of groundwater Shah (2017) also attempted identification of recharge area and groundwater flow paths and source of karstic springs.

HYDROGEOLOGY AND WATER RESOURCES OF THE BENGHAZI PLAIN:

Benghazi is the second most important city located on the Mediterranean coast in Libya North Africa. The author of the present paper had the opportunity to work with Ministry of Dam & Water Resources of the Government of Libya during 1975 to 1979).

The study area of the karstic aquifer in the Benghazi Plain (M.Y.Khan 1978) lies between 32° 15' and 31° 58' N latitudes and is bounded on the west by the Mediterranean Sea and on the east by the First Escarpment of the Jabal Al Akhdar. Surface rocks of the plain are of Middle Miocene age and are represented by the Benghazi Member of the Ar Rajmah Formation; scattered Quaternary sediments overlie the Miocene rocks and are mostly present along the sea coast. The Miocene rocks arc free of plications in the study area and generally lie flat. Fractures and faults occur with significant north-south or 40 northwest-southeast trends. A north-south trending prominent fracture system lies along Ar Rajmah Sidi Mansur line. The karstified limestones of the Benghazi Member constitute the main aquifer and is underlain by greyish green marls and clays of Lower Miocene to Oligocene age. The Eocene aquifer is mainly constituted of fossiliferous and partially karstified dolomitic limestones.

The aquifer characteristics of Benghazi Plain Aquifer were collected from pump test carried out in the borewells located in the Benghazi plain area. In addition a long duration pump test was carried out in a groundwater extraction gallery constructed in Sidi Mansur area. The results of step drawdown test and aquifer performance test (pumping phase and recovery phase) were used to calculate the specific capacity, transmissivity and storage coefficient using unsteady state conditions from the bulletin by Kruseman and Deridder (1970). It is obvious that under natural conditions it is very difficult to have all conditions of non-equilibrium equations (Todd, 1959) satisfied. Particularly the Benghazi Plain Aquifer is heterogeneous with wide variation in drawdown due to pumping because of presence of karstification .However, theoretical knowledge on karstic aquifers was very limited during the period of study and hence the equations developed on the basis of Darcian equation were used to gather qualitative knowledge on the Benghazi Plain Aquifer.

In addition to pump test an attempt was made to evaluate aquifer characteristics from the extensive water level fluctuation data collected from coastal aquifer in the Benghazi Plain. Two major causes of water table fluctuation are fluctuation due to barometric pressure and fluctuation due to ocean tides.

Benghazi Plain Aquifer responds to both barometric pressure and ocean tides. Being under confined condition the water levels exhibit diurnal fluctuations under atmospheric pressure. Also being a coastal aquifer sinusoidal fluctuation of ground water level occur in response to tides.

Barometric Efficiency can be defined as the water level fluctuation due to unit change in atmospheric pressure. Thus,

$$B = (\gamma * Дh) / Дp$$

Where, B = Barometric Efficiency (fraction)

γ = Specific Weight of Water.

Дh = change in water level

Дp = change in atmospheric pressure

Barometric efficiency is related to storage coefficient by the following equation

$$S = (\alpha*\gamma*b)/ (E*B)$$

Where, α = Porosity

S = Storage Coefficient

B = Aquifer Thickness

E = Bulk Modulus of compression of water

During the period 05/09/75 to 23/09/75 the estimated value of average barometric efficiency was observed as 0.73. The average thickness of the aquifer is 70m and porosity is assumed as 0.1. The value of storage coefficient was calculated as 4.57 X 10^-5.

In coastal aquifers in contact with the ocean sinusoidal fluctuation of ground water levels occur in response to tides. The time lag tL of a given maximum or minimum after it occurs in the ocean can be obtained from the following equation:

$$tL = X*\{(t0 *S)/(4\Pi*T)\}\text{^}0.5$$

Where tL = time lag of a given maximum or minimum after it occurs in the ocean.

X = Distance of the point of fluctuation from shore.

t0 = Tidal Period.

S = Storage Coefficient

T = Transmissivity.

Applying the period of tidal wave and the time lag in Sidi Mansur Gallery during 12/09/75 to 13/09/75 the the transmissivity of the aquifer was calculated as 12.55*10^-3 Sqm/Sec

The transmissibility and storage coefficient values for different localities in the Benghazi Plain are presented in Table 3 Below :

LOCALITY	TRANSMISSIBILITY m^2/sec	Storage Coefficient
Escarpment (Sidi Khalifa to Wadi Gattara)	1.5*10^-3 to 5.1*10^-5	
Hawari	1.96*10^-4 to 9.44*10^-4	0.25*10^-3 to4.3*10^-3
Sidi Mansur	3.6*10^-4 to16.5*10^-3	4.75*10^-5
Benina	1.05*10^-4to 6.4*10^-3	

The Benghazi Plain Aquifer is a karstic aquifer where the pumping wells in karstic channel area show practically no drawdown. Thus the flow is far from laminar. This non-darcian feature was feature was examined by analysing step drawdown data. The resultant flow equation showing relationship between discharge and drawdown at different localities are presented in Table 4 below

LOCALITY	WELL NO	FLOW EQUATION
Sidi Mansur Gallery		Q = 18.6*S^0.61
Sidi Mansur	3389/II/D-7	Q = 3*S^0.79
Sidi Mansur	3389/III/326	Q = 9.5*S^0.51
Sidi Mansur	3389/III/327	Q = 2.93*S^0.79
Regima Project Area	3389/III/262	Q = 0.82*S^0.78
Beninah	3389/III/815	Q = 3.1*S^0.57
Beninah	3389/III/213	Q = 2.5*S^0.73
Hawari	3389/III/162	Q = 1.8*S^0.60
Hawari	3389/III/114	Q = 0.095*S^0.95
Wadi Al Hish	3389/II/H-13	Q = 1.75*S^0.74
Sidi KhalifaQasr Tawil	3389/III/809	Q = 8.8*S^0.6
Sidi Khalifa	3389/III/812	Q = 2.18*S^0.71

In laminar flow the discharge is expected to be directly related to the drawdown. In pure turbulent flow the discharge is expected to be relared to square root of drawdown. Thus the flow equations in the table 4 shows that the Benghazi Plain Aquifer is Mixed Flow Karstic Aqufer.This is also evident from the Specific Capacity values ranging from very high i.e. above 100 lit/sec/m to very low 0.1 lit/sec/m.

ACKNOWLEDGEMENT : The data on Benghazi Plain Aquifer are from project carried out in Benghazi Libya area during 1975 to 1979 under guidance of Mr Richard Davis FAO Consultant and Dr. M.Y.Khan team leader.The help received from Mr Abdul Gader Shagloof, Mr Sadulla Besari ,Mr Raohi Ismael El Bakhri , Mr T.S. taju and Mr D.V.N Raju are gratefully acknowledged.

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