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Understanding of Ground Water-Surface Water Relationship through the Analysis of Ground Water Flow System of Part of Bengal Delta

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Abstract

The study area is part of Ganges-Meghna Deltaic Plain of the largest in the world, enjoys monsoonal climatic conditions. The main aquifer (aquifer-1) is made up of unconsolidated mostly sandy materials with some finer sediment and is gradually coarsening downwards with gravels and pebbles at the bottom. Hydraulic characteristics indicator confined conditions for the smaller eastern part while leaky-confined conditions prevail elsewhere. The ground water elevation is highest in the east-central (Comilla town) region and this is primarily due to maximum withdrawal and partly due to partial blockage of ground water flow by the north-south trending Lalmai Hills located to the west of Comilla town. The complicated flow net structure and its behaviour suggest that all perennial rivers maintain direct hydraulic continuity with Ground Water. Flow-net analysis reveals that most rivers in its downstream show the characteristics of a gaining stream conversely upstream river sections feeds the ground water with few exceptions. The surface water contribution of Gumti River to ground water is estimated to be about =707616000 m^3/annum at Comilla and Jibanpur station for the year 1979-1980 and 1980-1981. The Muhuri River discharge measured at Parshuram shows a baseflow component of 38 percent. The general ground water flow directions are mainly towards west, south-west, north, north-west and south. This unique flow pattern has developed because of the variable sloping direction. The close correlation in hydraulic gradient suggests a similar distribution of resource potential in different regions and also indicates that most parts of the aquifer are well connected and the permeability does not change abruptly. A sparse distribution of equipotential line and small hydraulic gradient is indicative of higher resource potential. The pattern of change of fluctuation in the north decreases radially from the central maximum in contrast with the southern region where the pattern of change is almost opposite. The total amount of recharge in the form of effective infiltration (Ie = 560 mm/annum or 5.71 x 10^9 m^3/annum) calculated from the annual volumetric changes (Wy = 2.85 x 10^{10} m^3/annum).

Keywords: Aquifer; Delta; Confined; Leaky-confined; Flow-net; Transmissivity; Storativity; Base flow

Introduction

The need and demand for ground water has become of paramount importance both for increased nationwide irrigation practices and to make ground water more readily available for drinking purposes and in for continued development boom. During research period, there were about 95 monitoring wells drilled by BWDB (Bangladesh Water Development Board) scattered throughout the present project area, from which water levels were and still are measured systematically and regularly once a week. These monitoring wells are constructed in the elevated ground of the villages and urban areas usually above the maximum flooding level to avoid the inundation and contamination of the well.

The short term changes preferably called the changes of ground water level in space are explained using the weekly measurement of ground water level data for all the piezometric wells for the year 1985. Long term changes in ground water levels i.e. the changes of ground water level with time are explained using continuous eleven years data (from 1976-1986) and are presented in the form of long term ground water fluctuation.

The initial depth measurements to the water table are made not from Ground Level (GL) but from a convenient elevated point called the Measuring Point (MP). The parapet height (height from GL to the MP) was carefully taken into consideration when the depth of the water table was converted into elevation for the preparation of different types of potentiometric maps. Both qualitative and quantitative assessment and all other flow pattern behaviour analysis are based on the available data set.

Geology

The Bengal Basin is a large uplifted faulted block of Pre-Cambrian basement rocks covered in parts with Cretaceous and Tertiary Shelf sediments. Tectonic element of Bengal Basin (Figure 1) can broadly be divided into Shelf, Slope or Hinge and Bengal Fore deep [1,2]. The present study area occupies the north-eastern part of Barisal-Chandpur gravity high, the western part of the unfolded flank and the northern part of the Hatiya trough.

The Bengal Basin, a major geosynclinals feature, began to form in the Late-Cretaceous period (approx. 70 million years ago) and continues subsiding today. Sediments washed from the surrounding hills have filled this geosynclinals basin to depths exceeding 18 km (Figure 1).

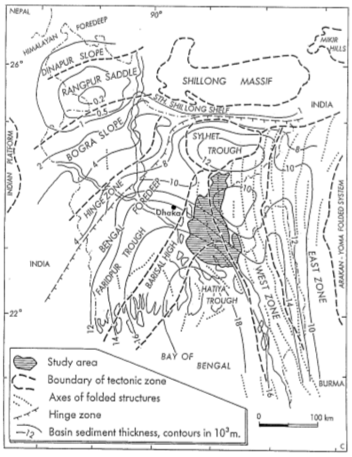

Figure 1: Tectonic and Sedimentary history of the study area (Guha 1978; Mirkhamidov et al., 1981).

No basement rock crops out within the study area (or in any part of Bangladesh as a whole) therefore the surface and sub-surface geology and geomorphology consists of these recent geosynclinals deposits. The Lalmai Hills are the only outcrop where all the rock types are exposed that makes up the sub-surface geology down to an investigated depth of around 150 m [3,4] of the area (Figure 2).

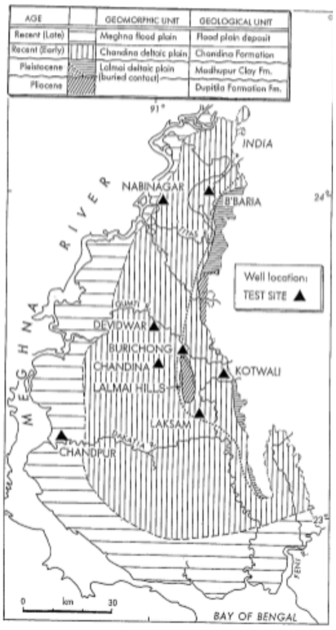

Figure 2: Geology, Geomorphology and Pumping will location of the study area (Source: Modified from Bakr, 1976).

The existence of several deep seated structures (folds and faults) has been identified with the Lalmai Hills as the only exposed structures. All those buried structures have very little or no control on the hydrogeological condition.

Hydrogeology

The occurrence of six well-defined potential aquifers [5] was identified down to a depth of >1800 m (Figure 3).

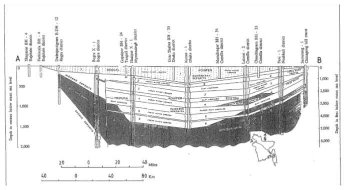

Figure 3: Geological Cross-section along "A-B" line showing the distribution of aquifers of Bangladesh (Source: Jones, 1985).

All these aquifers are made up of granular materials. The present work is entirely devoted to the delineation of the ground water resources of main aquifer (aquifer no 1). The natural distribution of the main aquifer in relation with the overlying aquiclude and the bottom clay aquitard is drawn along the A-B, B-C & C-D geological cross-section line (Figure 4).

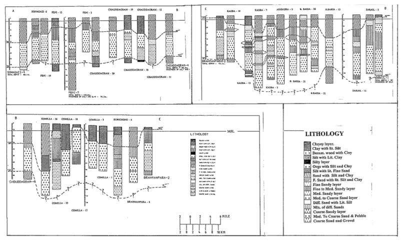

Figure 4: Correlation of Lithological units in the N-S direction along A-B, B-C and S-D line.

The entire study area in covered by the aquiclude with the exception of Lalmai hills and the average thickness ranges from 3 m to 300 m (Figure 5 (Right)). The average aquifer thickness ranges from 30 m to 120 m as revealed by aquifer thickness contour map (Figure 5 (Left)).

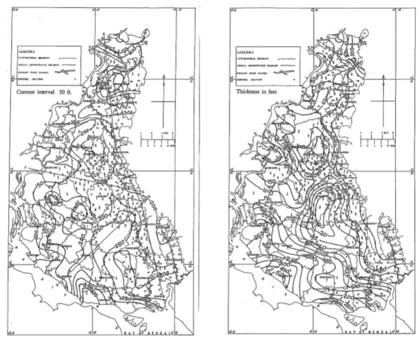

Figure 5: Left) Thickness distribution map of main aquifers; Right) Thickness distribution map of the surficial aquiclude.

The recharge and the ground water flow pattern are shown in an idealised sketch (Figure 6).

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The main aquifer is distributed as a continuous thick layer of sands but is separated locally into two or more layers which are more pronounced in the south-west. It is primarily formed of sandy Dupitila Formation, of Pliocene age, which is composed of unconsolidated sands showing a gradation of grain size. Finer sands are at the top with the sequence coarsening downwards; the coarse sand at the bottom is usually associated with gravels and pebbles.

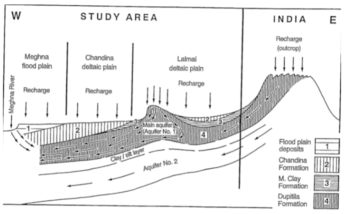

Figure 6: Idealised West-East Cross Section of the main aquifer showing recharge pattern.

Analysis of borehole pumping test data [6] indicate a true confined condition prevail in the smaller eastern part while leaky-confined conditions prevails elsewhere. The maximum and minimum Transmissivity ranges from >1400 m^2/d to < 400 m^2/d while the Storativity ranges from 4.1 x 10^{-3} to 3.7 x 10^{-4} and the maximum leakage (BL=368 m) is recorded in the central part.

The estimated total amount of recharge is about 1860 mm per annum and about 90% of which originates from direct infiltration of precipitation and influent seepage. The loss of ground water storage during the dry season is restored rapidly and regularly by the following monsoon recharge.

Minimum elevation flow-net analysis (dry period)

The contour map (Figure 7 (Left)) has been prepared for the driest periods (March, 1985) data. During this period of the year the water table reaches to its minimum elevation as a result of a long dry sunny winter (November to March) which is a consequence of the monsoonal climate. At the same time, a maximum amount of ground water is also withdrawn from ground water storage.

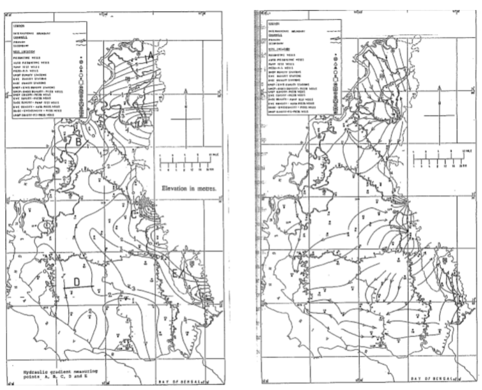

Figure 7: Left) Water Table contour map of Minimum Elevation (dry period), March 1985; Right) Major flow direction based on Minimum Elevation contour map, March 1985.

The constructed flow pattern (Figure 7 (Right)) is very complicated and difficult to analyse yet it provided useful information to establish the possible relationship between the ground water and surface water and the preferential flow directions. In the northern region, the northern part of the Titas River behaves like a gaining stream while the southern part that merges with the Meghna River provides clear indication of a losing stream. The contribution to or from the Gumti River is somewhat unclear. The upstream part of the Dakatia and most parts of the Little Feni River show clear indications of a losing stream. The flow pattern of the Noakhali Canal provides clear indication of a gaining stream.

A clear contrast in contour spacing is visible between eastern and western part of the study area. The contour in the western part are sparsely (thinly) distributed in comparison with those of the eastern part. The extreme closeness of the contours around Comilla town (well-49, 52 and 60) is mainly because of excessive unplanned withdrawal of ground water from storage rather than because of poor aquifer conditions. The hydraulic gradient has been calculated for five different locations (Table 1) covering contrasting regions (Figure 6).

Period	Location	Hydraulic Dh/dl = i	Gradient Ratio
Dry Period	A	$3.26 * 10^{-4}$	1:3070
"	B	$1.09 * 10^{-4}$	1:9140
"	C	$1.27 * 10^{-3}$	1:790
"	D	$7.18 * 10^{-5}$	1:13930
"	E	$2.86 * 10^{-4}$	1:3500

Table 1: Measured hydraulic gradient at selected locations during Dry Period (March, 1985).

Locations A, C and E were selected from eastern densely distributed contoured area and while locations B and D were chosen from the sparsely distributed contoured are. The maximum and minimum hydraulic gradient values are recorded at locations C and D respectively which have a difference of more than two orders of magnitude. A number of reasons could be advanced to account for the steeper gradient in the eastern region and particularly at location C (around Comilla town).

Firstly, the town is a densely populated area which has a high demand for water for municipal purposes all year round.

Secondly, the urban area is surrounded by highly fertile crop lands which also require constant irrigation during dry season for which the major source is ground water.

Thirdly, a considerable amount of ground water is also abstracted for industrial purposes. As a consequence the hydraulic gradient sharply increases within the zone of influence of this cluster of wells.

Maximum elevation flow-net analysis (wet period)

This contour map (Figure 8 (Left) has been prepared using the water table measurements for August, 1985 when the maximum amount of rainfall occurs. During this period of time the highest possible amount of recharge takes place and in a few cases, particularly close to the flood plain area, some land surface occasionally becomes inundated.

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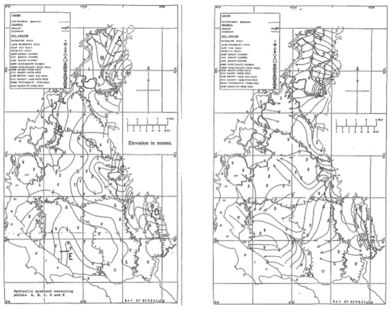

Figure 8: Left) Water Table contour map of Maximum elevation contour map, August 1985; Right) Major flow direction based on Maximum elevation (wet period), August 1985.

In this map the general flow is more clearly defined. An interesting feature about the ground water flow is observed within the 4 m closed contour surrounding Nabinagar and Muradnagar areas in the north-west (Figure 8). Here it looks as if ground water is pouring in from all directions. This 4 m contour surrounds the downstream part of the Gumti River suggesting the river is being fed by the ground water but the reverse is true for the upstream part of the same river. Based on wet period flow-net the Titas River becomes a major contributor to ground water throughout its entire length. The downstream section of the Dakatia River and most parts of the Noakhali Canal show the characteristics of a gaining river. The losing characteristics of the Little Feni River are consistent with the dry period interpretation. The Feni River in the light of this flow-net analysis has characteristics of a gaining river.

Period	Location	Hydraulic dh/dl = i	Gradient Ratio
Dry Period	A	$3.18 * 10^{-4}$	1 : 3140
”	B	$2.08 * 10^{-4}$	1 : 4780
”	C	$3.50 * 10^{-4}$	1 : 2860
”	D	$2.75 * 10^{-4}$	1 : 3640
”	E	$2.72 * 10^{-4}$	1 : 3680

Table 2: Measured hydraulic gradient at selected locations during Dry Period (March, 1985).

The equipotential lines are much more uniformly distributed and the spacing of the contours all over the project area is somewhat similar. Even in the urban areas (around Comilla town) the contour spacing has also increased significantly to give a better co-ordination with the other areas. The hydraulic gradient has been calculated for five different locations (Table 2) below which are close to those considered previously. The wet period values are remarkably close to each other and they are also fairly small.

Annual fluctuation map

The fluctuation map (Figure 9) reveals that the maximum amount of fluctuation (>10 m) has occurred in and around the Comilla town. The minimum amount of fluctuation is as low as zero (0) m is recorded in the northern part of Nasirnagar area. Further north, close to the boundary an area of negative fluctuation (-1 m) is recorded which implies a rise in water level during dry period. This seems to be unlikely on the basis of the prevailing condition, when the water table elevation is expected to be declining. A possible explanation for the rising water table could be that more water is coming into storage *via* horizontal flow and deep percolation as well as from the effluent Titas river than the amount of water that is flowing out naturally and/or taken out from storage by pumping through the existing number of wells.

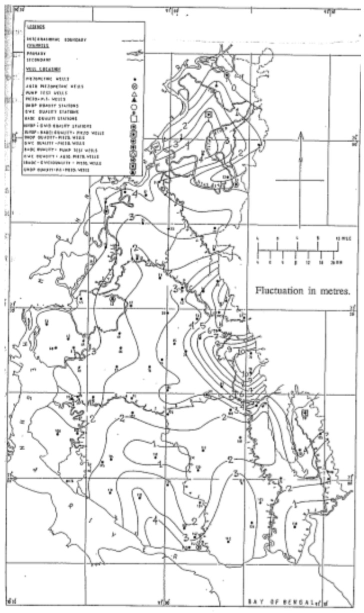

Figure 9: Contour map showing annual water table fluctuation for 1985.

The changing fluctuation pattern in the north is quite different from those in the south. In the north, the maximum fluctuation is intermediate and gradually decreases in all directions. However, for the larger southern part the reverse is true i.e. the central part gave rise to the lowest fluctuation and increases on all other direction except the south-eastern narrow strip where the fluctuation decreases into the Feni River, which itself behave as a gaining river. The contour spacing of the annual fluctuation contour map increases in the west, north-west and south-western directions, in similar fashion to the contour spacing of the dry period elevation contour map (Figure 7 (Left)). In all locations the increased amount of fluctuation has coincided with the higher amount of ground water withdrawal. A controlled high withdrawal in relation to the annual recharge makes more ground water available for use.

Long term trend in ground water level response

The graphical representation of long term change of ground water level demonstrates the changing behaviour under prevailing conditions. Three different monitoring wells were chosen to represent long term changing trend using 10 years data from January 1976 to December 1986; these are monitoring Well-4, Well-58 and Well-142 (Figure 10).

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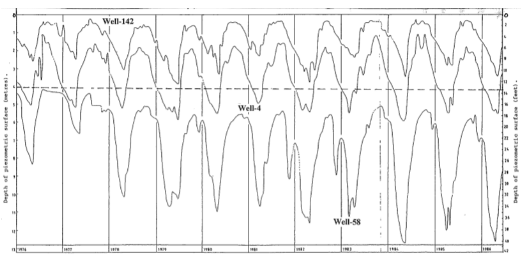

Figure 10: Water Table map using 10 years (1975-1986) measurement showing long term trends.

The upper limit of this fluctuation graph coincides with the measuring point level of monitoring well 4 (0 m mark, the upper bounding line) and the graduation scale for this graph is also prepared with respect to this well. The measuring point level for monitoring well 58 is actually at the 4 m marked level in the vertical scale. In the same way the measuring point level for the monitoring well 142 is actually 0.5 m above the upper bounding line of the figure indicating that maximum water levels come close to the surface. A brief description about the water level behaviour for each of these wells is presented below:

Well number 4

This well is located in the extreme northern part of the project area. This well shows no consistent long-term decline in ground water level. An examination of the seasonal rise of maximum water level during the last ten years (Figure 10) reveals the following facts. There was a steady decline of maximum water level for four years from 1975-1976 to 1979-1980 but during the next two water years (1980-1981 and 1981-1982) a rise of maximum water level was recorded.

A brief fall of maximum water level in 1982-1983 water year is followed by a rise during the next two water years (1983-1984 and 1984-1985) and again a fall in maximum water level is noticed during the 1985-86 water year. This alternate rise and fall of maximum water level is not at all affected by the continuously rising number of irrigation wells responsible for a steady increase in ground water withdrawal. This indicates that the amount of withdrawal is low in comparison with the perennial yield.

Well number 58

This well is installed in the highly populated Comilla town area in the east-central region where there is a great demand for ground water for both municipal and agricultural purposes. Like many others, well-58 is under constant use throughout the year to meet the ground water requirements for municipal and other purposes. Because of excessive annual abstraction this well produces the maximum amount of fluctuation (7.0 m or >23 ft). An examination of the maximum water level during the last ten years (Figure 10) reveals the following information.

A steady decline of maximum water level was recorded for a period of four years from 1975-1975 to 1979-1980 and thereafter maximum water levels recorded a rise for the next two water years (1980-1981 and 1981-1982) followed by a brief fall during the 1982-1983 water year.

A substantial rise in maximum water level was recorded during the 1983-1984 water year. Although not high enough to reach the level of 1976-1977 water year it was higher than during the last six years of record and was followed by a decline of maximum water level during 1984-85 and 1985-1986.

These alternate declines and recovery of maximum water level are a positive indication that the seasonal dry period overdraft of ground water storage is recoverable in spite of the heavy withdrawal of ground water which is primarily a consequence of the existing management practice of ground water resources. It can be regarded as a local phenomenon rather than of regional significance.

This effect can easily be understood from the opposite behaviour of the maximum water level in the other two wells. The lowering of the water table also emphasises that the amount of ground water withdrawal is greater than the seasonal replenishment.

Well number 142

This well is located in the extreme southern part of the study area in Noakhali town (Sudharam Thana). In the Noakhali district there are fewer wells in the south but the number of wells progressively increases further inland towards north. Ground water irrigation in the south takes place on a much smaller scale, there-by suggesting a much lower abstraction.

All these facts are revealed in the form of the long term fluctuation trend (Figure 10). Well-142 shows a small but continuous steady rise in maximum water levels during the six years from 1979-1980 to 1985-1986 in spite of the limited seasonal amount of artificial withdrawal of ground water.

The seasonal dry period losses are fully recharged during the following wet period where the replenishment at the same time increases the perennial yield from this particular well.

Replenishment calculation

The yearly replenishment for the year 1985 is calculated using the prepared fluctuation contour map (Figure 9). The replenishment is calculated in the form of volumetric changes multiplying the area involved by the average fluctuation (Table 3).

The total volumetric change in the contours between the extremes of -2 and +11 m is equivalent to some 28, 500 million m^3 [= 2.85335 x 10^{+10} m^3].

Finally the total amount of recharge in the form of effective infiltration (Ie) is calculated using the follow relationship:

Ie = [(Wy x Sy)/a] to get the results in terms of height in (mm/year), and

Ie = (Wy x Sy) to get the results in volume in (m^3/year).

Where, Wy = total volumetric changes = (2.85335 x 10^{+10} m^3), a = area over which recharge occurred = (1.02235 x 10^{+10} m^2) and Sy = specific yield = 20 percent.

When the aquifer is fully unconfined the specific yield can be determined directly from pumping test analysis but for the study area the aquifer is under leaky confined to confined condition. The specific yield can be derived from measuring the porosity of the aquifer material. In the absence of measured porosity data, three different sources were reviewed to consider a value of 20 percent.

Contour Interval (m)	Area Between Contours (m^2)	Average Fluctuation (m)	Volumetric Change (m^3)
-2 to-1	8.95×10^{7}	1.5	1.343×10^{8}
-1 to +0	1.80×10^{8}	0.5	9.000×10^{7}
+0 to +1	5.49×10^{8}	0.5	2.745×10^{8}
+1 to +2	1.78×10^{9}	1.5	2.670×10^{9}
+2 to +3	4.15×10^{9}	2.5	1.038×10^{10}
+3 to +4	2.26×10^{9}	3.5	7.910×10^{9}
+4 to +5	6.42×10^{8}	4.5	2.889×10^{9}
+5 to +6	1.61×10^{8}	5.5	8.855×10^{8}
+6 to +7	1.34×10^{8}	6.5	8.710×10^{8}
+7 to +8	9.72×10^{7}	7.5	7.290×10^{8}
+8 to +9	7.40×10^{7}	8.5	6.290×10^{8}
+9 to +10	5.02×10^{7}	9.5	4.769×10^{8}
+10 to +11	5.66×10^{7}	10.5	5.943×10^{8}

Table 3: Volumetric changes covering the entire region.

The specific yield determined for sand, sand & gravel and gravel & sand is about 20 percent [7]; experimentally established specific yield for the present aquifer material [8] ranges from 15 to 25 percent; same values were reprinted by [9,10] has compiled an average value of 25 percent for samples in various geographic locations. The average of this published value is about 22 percent but to be on the safe side a specific yield value of 20 percent has been accepted to avoid over estimation. Using this specific yield value the calculated value of effective infiltration (Ie) in both forms are:

$$Ie = [(Wy \times Sy)/a] = [\{2.85335 \times 10^{+10} \times 0.20\} / 1.02235 \times 10^{+10}]$$

$$= 558.22 \text{ mm} = 5.71 \times 10^{+9} \text{ m}^3.$$

Influent seepage of surface water

The influent seepage is that component of Ground Water that is derived from Surface Water Bodies. This component has been calculated by measuring the river discharge at two different points [11-14]. The upstream discharge measuring point for the Gumti River is at Comilla Town (BWDB station 110) and the downstream discharge measuring point is at Jibanpur (BWDB station 114).

The average total amount of flow at these two stations for the year 1979-1980 (Figure 11) and 1980-1981 (Figure 12) is 1170 cumec-days/annum. The total amount of influent seepage is estimated to be about: 707616000 m^3/annum.

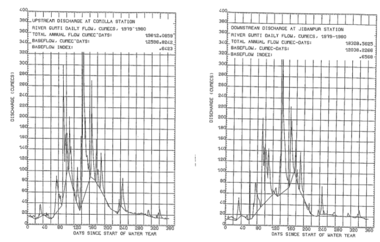

Figure 11: Hydrograph showing the baseflow and surface run-off components for 1979-1980 (Comilla and Jibonpur Station).

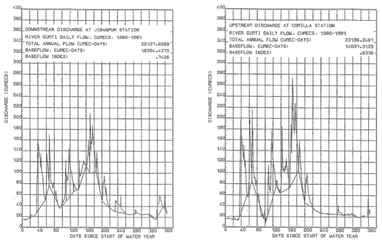

Figure 12: Hydrograph showing the baseflow and surface run-off components for 1980-1981 (Comilla and Jibonpur station).

Effluent flow to surface water bodies

The quantity of surface water that is derived from ground water source is termed as effluent flow or base flow. This amount has been calculated by analysing and separating hydrograph using a computer program developed by U.K. Institute of Hydrogeology (1978).

The Gumti River discharge was measured at Comilla Town (BWDB station 110) and at Jibanpur (BWDB station 114). For the year 1979-1980 (Figure 11) and 1980-1981 (Figure 12) with a base flow component of 67 percent (Table 4).

Type	Period	Zones	Zonal flow	Tot. Inflow (Comec/year)	Type	Period	Zones	Zonal Flow	Tot. Outflow (Comec/year
	Wet	Zone1	$4.3*10^{6}$			Wet	Zone1	$1.5*10^{6}$	
	”	Zone2	$4.8*10^{6}$			”	Zone2	$3.7*10^{6}$	
	”	Zone3	$3.6*10^{6}$	$2.6*10^{7}$		”	Zone3	$7.3*10^{6}$	$2.1*10^{7}$
Sub-	”	Zone4	$3.6*10^{6}$		Sub-	”	Zone4	$3.7*10^{6}$	
surface	”	Zone5	$4.9*10^{6}$		surface	”	Zone5	$5.2*10^{6}$	
In-	Dry	Zone1	$3.1*10^{6}$		Out-	Dry	Zone1	$2.4*10^{6}$	

Flow	”	Zone2	$1.5*10^6$		Flow	”	Zone2	$4.4*10^6$	
	”	Zone3	$2.1*10^6$	$1.9*10^7$		”	Zone3	$3.4*10^6$	$2.1*10^7$
	”	Zone4	$1.5*10^6$			”	Zone4	$3.3*10^6$	
	”	Zone5	$4.8*10^6$			”	Zone5	$4.3*10^6$	
	”	Zone6	$5.9*10^6$			”	Zone6	$3.7*10^6$	
	Average	Total	Inflow	$2.3*10^7$		Average	Total	Outflow	$2.1*10^7$

Table 4: Sub-surface inflow and Outflow of Ground water along various Zones across boundary.

The Muhuri River discharge measurement was considered for the year 1980-1981 & 1982-1983 (Figure 13) measured at Parshuram station (BWDB station 212) with a base flow component of 38 precent.

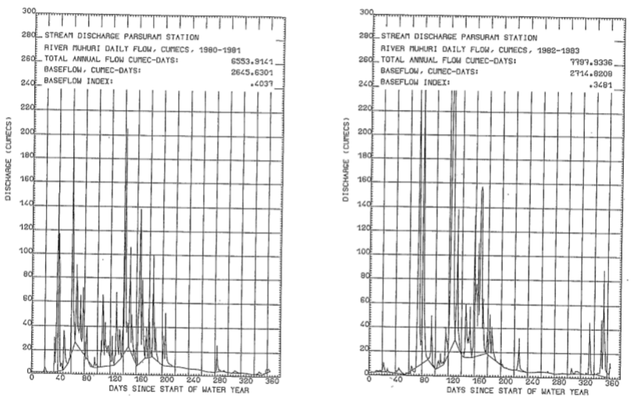

Figure 13: Hydrograph showing the baseflow and surface run-off components for 1980-1981 (Parsuram Station).

Subsurface inflow and outflow across aquifer boundaries

Due to hydraulic continuity between surface water and ground water subsurface inflow and out flow takes place across the aquifer boundaries of hydrogeological regime from area of higher to lower potential head [15]. The two parameters obtained from flow net are the hydraulic gradient (i=dh/dL) of the adjacent pair of contours and the length of the equipotential line which effectively represent the actual length of the inflow and outflow zones (L).

The third parameter is the Transmissivity (T) of that part of aquifer obtained from pumping test analysis. These three parameters are used in the most convenient form of Darcy's law (Q=T*i*L) to make the assessment.

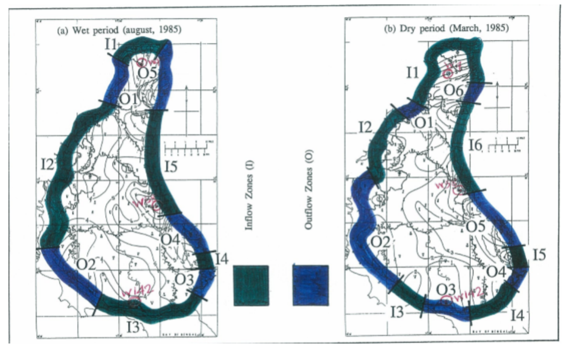

Figure 14: Map showing the Sub-surface peripheral inflow and outflow zones.

Five (5) different zones for Dry Period and six (6) different zones for Wet Period (Figure 14) have been recognised from the constructed flow-nets. The total volume of average basin inflow is $2.3*10^7$ m^3/year. Over the Basin the total volume of average outflow is $2.1*10^7$ m^3/annum.

Conclusion and Recommendation

The seasonal dry period loss of ground water storage is restored rapidly and regularly by the rising water table conditions. An interrupted rise of maximum ground water level is recorded in the north but the water level in the southern region shows a small but continuous rise of maximum water level indicating increased availability of temporary storage [16-18]. The limited small scale decline of maximum water level in the east-central (Comilla town) region seems to be primarily because of excessive unplanned annual abstraction and can be regarded as a local event. Further study is recommended to determine the exact nature and extent of the problem.

It is clearly visible that all rivers maintain active hydraulic continuity with ground water and one resource compliments the other one. It can be concluded from flow-net analysis that most rivers in its downstream sections show the characteristics of gaining streams while the upstream sections show the reverse characteristics with few exceptions [19]. The surface water contribution of Gumti River to ground water is estimated to be about: 707616000 m^3/annum in between discharge measuring station at Comilla Town (BWDB station 110) and Jibanpur (BWDB station 114) for the year 1979-1980 and 1980-1981.

The hydrograph separation of Gumti river discharge measured at Comilla Town (BWDB station 110) and at Jibanpur (BWDB station 114) for the year 1979-1980 and 1980-1981 shows that ground water contributes about 67 percent of its flow. The Muhuri River discharge measured at Parshuram station (BWDB station 212) shows a base flow component of 38 percent.

Other than the general direction some flow of ground water is found to be towards eastern direction, which defied logical explanation. This problem could be primarily either due to improper measurement of water level of the ground elevation was not properly determined which require further investigation of both parameters [20,21]. If the contour maps could be extended towards the natural ground water divides which are located further east in India, by including more ground water records from the Indian part, then the true flow pattern would be better understood.

A high withdrawal is not necessarily harmful for the aquifer. In fact a controlled high withdrawal in relation to the annual recharge makes more ground water available for use. On the other hand, the excess amount of recharge which was previously unable to be taken up into storage because of early saturation could now be accepted by the aquifer by virtue of the creation of more space by excessive withdrawal.

Porosity measurement of aquifer material is highly recommended that will allow more accurate estimation of specific yield and the calculation of effective infiltration. More study is recommended to understand the recharge mechanism through surficial aquiclude to quantify effective infiltration more accurately.

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