ZENITH International Journal of Business Economics & Management Research
Vol.2 Issue 7, July 2012, ISSN 2249 8826
Online available at http://zenithresearch.org.in/

BASIC WATER REQUIREMENT AND WATER BUDGET STUDY OF BAC NINH PROVINCE (VIETNAM)

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ABSTRACT

Careful use of the limited fresh water resources is the need of the hour. If sufficient measures are not taken up immediately, we will face a crisis which will be detrimental to the very survival of mankind. The Bac Ninh Province of Vietnam is facing a similar problem of acute shortage of drinking water. The water resources in this study area have been estimated by water balance assessment approach. The water balance study using the Thornthwaite and Mather (TM) models with the help of remote sensing and GIS is very helpful in finding out the moisture deficit and moisture surplus for an entire province. The water balance calculation shows that the maximum annual runoff results from the built-up areas/water body followed by agricultural land, and minimum for the barren land and open forest. The annual deficit in the Bac Ninh Province is 1362.2 mm and the annual surplus is 552.7 mm. The total runoff of Bac Ninh Province was calculated as 564.2 mm from the total precipitation of 1384.2 mm. The annual surface water availability for Bac Ninh Province works out at 564.23 mcm. Deducing 5%, which is usually regarded as natural discharge during non-monsoon months, thus region as 536.02 mcm as surface water availability. The current gross demand as drinking & domestic, irrigation purpose / agricultural used, and industrial used is 347.52 mcm (64.83%). The balance surface water availability for future development in the Bac Ninh Province is 188.50 mcm.

KEYWORDS: Water Budget, Water Balance, Thornthwaite Method, Residual Mass Curve, and Surface Water Availability.

1. INTRODUCTION

Water is the most precious gift of nature to the mankind and has been recognized as one of the most vital natural resources. It is not so just because water sustains life but it is a renewable resource. It is also the most essential input for agriculture industry and power generation. The availability of water with proper quality and quantity at appropriate time and space are of great importance. The water management is very essential to maintain quality, quantity and the availability of water due to increase in population, rapid urbanization & industrial growth. Though its availability is limited yet demand for water is ever increasing. It has direct impact on human being and socio-economic development. Hence, the need of proper planning management of the precious resource has become the matter of utmost urgency.

The water balance has been used for computing seasonal and geographic patterns of irrigation demand the soil moisture stresses under which crop and natural vegetation can survive. Water table calculated for a single soil profile or for an entire catchment, refers to the balance between incoming of water by precipitation and outflow of water by evapotranspiration, ground water recharge and stream flow. Among the several possible methods of calculation, the one introduced by Thornthwaite and Mather (1957) generally has been accepted. This technique uses long term average monthly rainfall, long term average potential evapotranspiration, and soil and vegetation characteristics. The last two factors are combined in the water capacity of the root zone.

The water balance is useful for predicting some of human impacts on the hydrologic cycle. The hydrologic effects of weather modification or changes of vegetation cover can be quickly estimated at a very early stage in the planning. Although the predictions may be approximate, they are sufficiently accurate to indicate whether a scheme is hydrologically sound or none. Also the water balance can be refined to meet the most sophisticated design needs if sufficient time and money for instrumentation are available. Finally the method is valuable for helping to phrase precise questions about the chances of success, mode of operation, and environmental impact of proposed changes. It is, therefore, a valuable tool in the analysis of water problems in a region.

In the last few decades, changes in land use and land cover, changes in climatic conditions, population explosion, enhanced industrialization and urbanization has deteriorated the conditions of the watersheds in Bac Ninh Province, Viet Nam. As a result, the effect of these changes on the water balance components is unknown. A serious problem recognized is that sufficient water is not available during the dry season. The water sector is very sensitive and is strongly influenced by the changes in climate and land use. Hence, it has the potential to impose additional pressures on water availability, water accessibility and water demand in that area. Even in the absence of climatic change, present population trends and patterns of water use indicate that the area will exceed the limits of the economically usable, land based water resources before 2030. It is important to bridge the gap either by reducing the demand or by increasing the supply level to match the growing demand in future. Mechanisms must be developed for allocating the scarce water resources between the competing demand such as irrigation/agricultural, rapidly expanding domestic and industrial needs, hydropower and environmental requirements.

2. BACKGROUND INFORMATION

Bac Ninh Province is located in the Red River Delta region. It is surrounded by Bac Giang Province to the north, Hung Yen Province to the south, Hai Duong Province to the east, and Hanoi to the west (Fig. 1). The topography is quite flat with a complex network of rivers and springs, including Cau, Duong, and Thai Binh rivers. Bac Ninh has the weather of monsoon and clearly divides into four main seasons i.e. spring, summer, autumn and winter. There are also two main seasons: rainy season that lasts from May to October and dry season lasting from December to April next year. The average temperature of a year is approximately 24°C. The highest one is 30°C in July; the lowest one is 15°C in January. The annual average rainfall is 1,400 mm - 1,600 mm. Bac Ninh Province is 30 km from Hanoi,

110 km from Hai Phong, 20 km from Bac Giang Province, and 45 km from Noi Bai International Airport. It is on the National Highway No.1A, 18, 38. The general information of the study area is shown in Table 1.

TABLE 1: GENERAL INFORMATION OF THE STUDY AREA

Area	**823.13 Sq. Kms.**
Population	**1024.23 thousand habitants (April 2009)**
Capital	**Bac Ninh City**
Town	**Tu Son**
Districts	**Que Vo, Yen Phong, Tien Du, Tu Son, Thuan Thanh, Gia Binh, and Luong Tai**
Ethnic Groups	**Viet (Kinh), Tay, Nung, Muong**
Economy	**Agriculture**
Average Temperature	**24^0C**
Average Annual Rainfall	**1,400 mm to 1,600 mm**

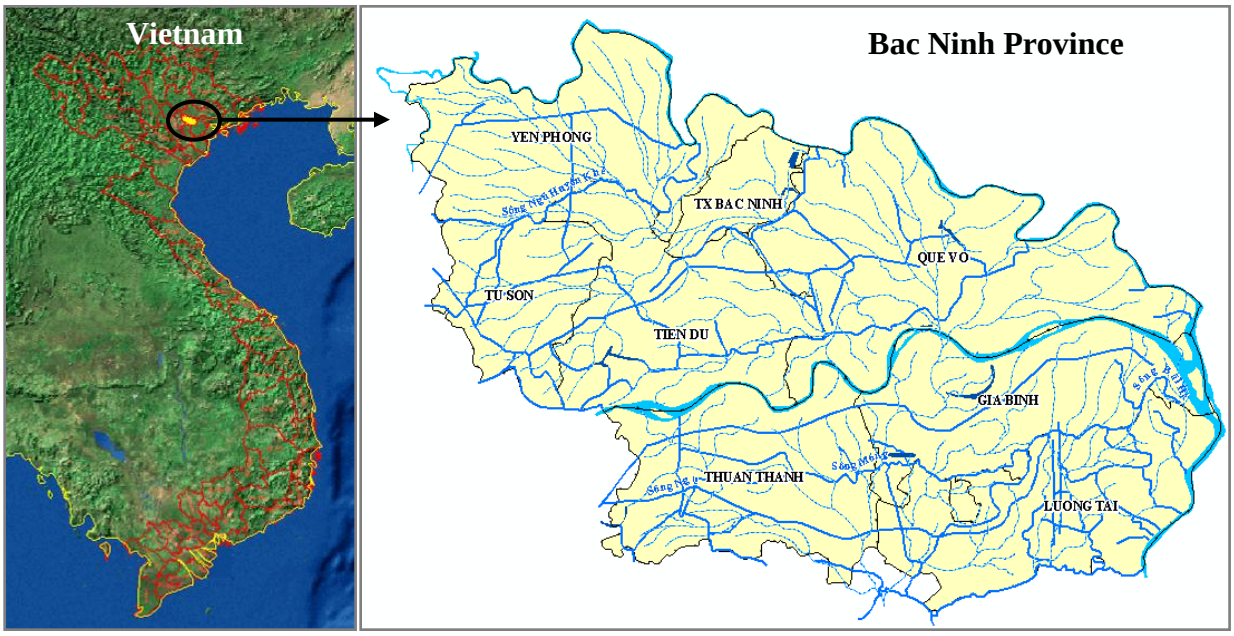

FIGURE 1: LOCATION MAP OF THE STUDY AREA

3. THE WATER BUDGET

Water covers 70% of the earth's surface, but it is difficult to comprehend the total amount of water when we only see a small portion of it. The oceans contain 97.5% of the earth's water, land 2.4%, and the atmosphere holds less than .001%, which may seem surprising because water plays such an important role in weather. The annual precipitation for the earth is more than 30 times the atmosphere's total capacity to hold water. This fact indicates the rapid recycling of water that must occur between the earth's surface and the atmosphere.

A water budget is a formal definition of the quantity of water that would be required by an efficient level of water use (AWE, 2008). Water availability is very much dependent upon climate conditions, especially precipitation and temperature (Fig. 2). Scientists cannot predict with confidence climate conditions decades ahead, but plausible climate scenarios can be constructed based on assumptions that climate conditions observed in the past could recur, and that climate projections made by global climate models have some validity (EPA, 2010). A water budget is a site-specific method of calculating an allowable amount of water to be used by the landscape and then designing the landscape to meet this budget. The budget takes into account plant type, plant water needs, agricultural need, industrial need, human need, irrigation system design, and applied water that the landscape receives either by irrigation or by precipitation. Water budgets must be associated with a specified amount of time, such as a week, month, or year.

Water budgets in Bac Ninh Province are variable from year-to-year, decade-to-decade, and over centuries and millennia. Variations and changes in climate, geology, soils, vegetation, and hydrology have produced different inputs, storages, and flows of water. Similarly, it

can be expected that water budgets will change as land cover and climate change, and as water withdrawals and diversions occur.

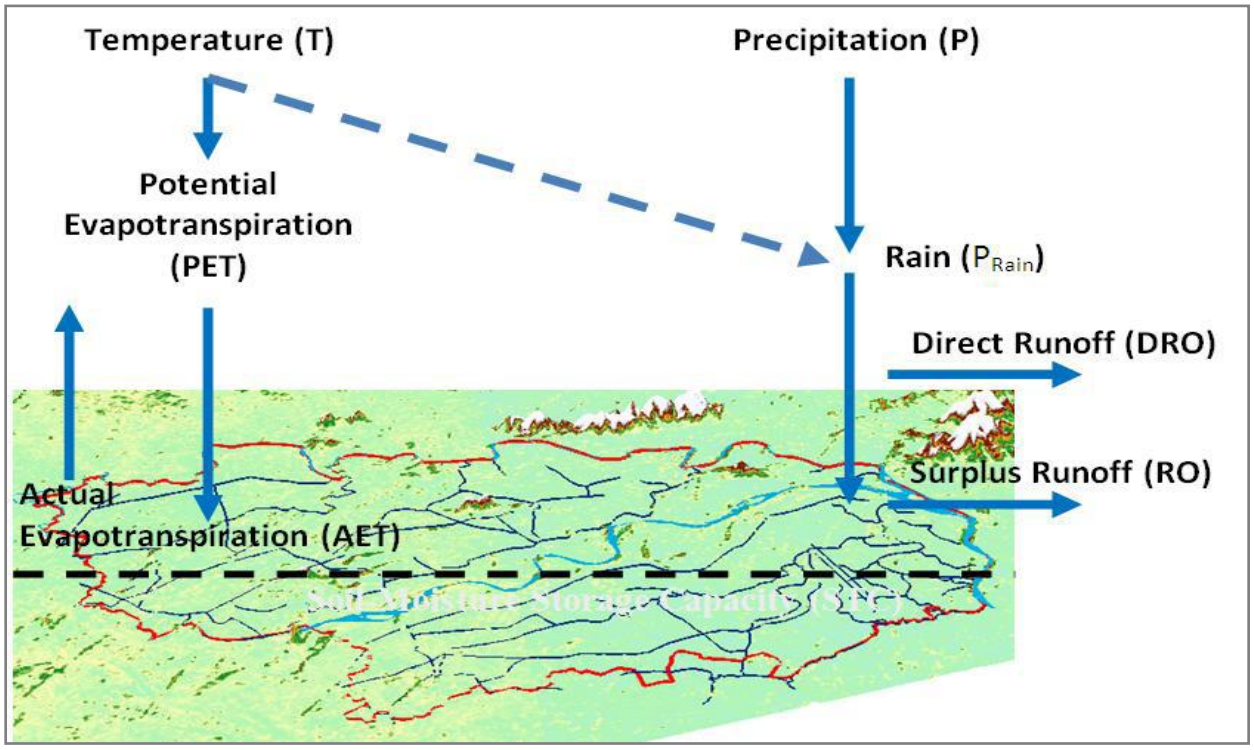

FIGURE 2: COMPONENTS OF THE WATER BALANCE ON REGION

4. DATA USED AND SOURCES

Base Map: QuickBird satellite imagery with 60cm spatial resolution, and topographical map at 1:50,000 scale.

Land Use / Land Cover Map: Digitally land use and land cover map has been prepared using knowledge classification method in ERDAS IMAGINE 2010, and satellite remote sensing data i.e. IRS-P6 (ResourceSAT-1) LISS-IV Mx satellite imagery with 5.8m spatial resolution, and LANDSAT-7 ETM$^+$ satellite imagery with 30m spatial resolution.

Geological Map: Bac Ninh Geological Map has been collected from Department of Geology & Minerals of Vietnam and updated through IRS-P6 LISS-IV Mx satellite remote sensing data with limited field check.

Slope Map: Slope map has been created using Spatial Analyst Extension in ArcGIS-10 software, and ASTER (DEM) data with 30 m spatial resolution.

Drainage Map: Drainage network has been generated in GIS environment using ASTER - DEM data and ArcHydro Tool in ESRI ArcGIS-10 software.

Climatic Data: Precipitation and temperature data have been collected from National Climatic Data Center (NCDC).

Demographic Data: General Statistics Office of Vietnam.

5. METHODOLOGY

The water budget is useful for predicting some of human impacts on the hydrologic cycle. Many models are available for computing runoff or water budget in a watershed. SCS curve number method, soil moisture accounting model, green ampt model, penman-monteith method, thornthwaite and mather model, etc., are very popular models used for computing runoff. All these models take the information derived from the remote sensing data. Thornthwaite and Mather Model are widely used for computing water budget. It can be applied for big size watershed as Bac Ninh province area.

C. W. Thornthwaite (1955) worked with the water balance approach to assess water needs for irrigation and other water related issues. Water balance methodology has been used in a lumped watershed scale in order to develop climate classifications. The main parameters of Thornthwaite and Mather Model are described below:

- **Mean Monthly Temperature (C), $C = (m / 30) * (d / 12)$**
- **Heat Index (I), $I = (T / 5)^{1.514}$**
- **Potential Evapotranspiration (PET), $PET = 16 * C * (10 * T / I)^{a}$, Where, a = 6.75 * 10-7 * I3 - 7.71 * 10-5 * I2 + 1.792 * 10-2 * I + 0.49239**
- **Accumulated Potential Water Loss (APWL), $APWL = (P\text{-}PET) + APWL_{PreviourMonth}$**
- **Available Water Capacities (AWC), AWC = Based on land use, soil, rooting depth, 153.57**
- **Actual Storage of Soil Moisture (STOR), $STOR = AWC * e^{(APWL / AWC)}$**
- **Changes of Actual Storage (ΔSM), $\Delta SM = STOR_{Month} - STOR_{PreviourMonth}$**
- **Actual Evapotranspiration (AET), $AET = \Delta SM + P \quad \Delta SM<0, AET = PET \quad \Delta SM>0$**
- **Water Deficit (DEF), $DEF = PET - AET$**
- **Surplus (SUR), $SUR = P - (AET + \Delta SM)$**
- **Available Runoff (ARO), $ARO = ARO_{PreviourMonth/2} + SUR$**
- **Runoff (RO), $RO = ARO / 2$**
- **Detention (DET)**

Author has determined the water balance of Bac Ninh Province by using Thornthwaite and Mather Model, and shown in Table 2.

As per Thornthwaite & Mather Model output average annual water accumulation, annual water runoff, and the annual surface water availability of Bac Ninh Province are shown in Table 3.

For preparation of residual mass curve for Bac Ninh Province (Viet Nam), the annual rainfall for 14 years (1998-2011) has been considered. The average rainfall for a period of 14 years works out 1409.46 mm for Bac Ninh Province, which form zero base lines for the residual mass curve for respective location. The residual mass curve has been prepared and shown in Figure 3. A glance at the residual mass curve is indicating the very poor condition for annual groundwater increment during the above maintain period.

6. RESIDUAL MASS CURVE

Ground water growth study of the Bac Ninh Province has been done through the residual mass curve, which has been prepared by taking the cumulative departure from the average annual rainfall against the number of month/years on an ordinary graph paper, may be divided into different cycle based on the departure from the average annual rainfall. The parts of the curves, which are above the base line, (representing the average annual rainfall for the number of month/years under consideration) indicates better period of recharge and filtration condition for the groundwater bodies.

TABLE 2: PRECIPITATION, TEMPERATURE, WATER DEFICIT, SURPLUS, AND AVAILABLE RUNOFF

Year	DEC	NOV	OCT	SEP	AUG	JUL	JUN	MAY	APR	MAR	FEB	JAN	Thornthwaite & Mather Model Parameters
1,384.2	19.9	4.2	100.9	184.0	447.8	221.3	130.9	133.1	51.0	5.4	7.0	78.9	Precipitation (in mm) (Year - 2010)
289.0	19.0	22.0	25.0	28.0	29.0	29.0	30.0	28.0	24.0	20.0	18.0	17.0	Temperature (T) 0C (Average Mean)
365.0	31.0	30.0	31.0	30.0	31.0	31.0	30.0	31.0	30.0	31.0	28.0	31.0	Number of Day / Month (m)
93.9	8.0	9.5	9.4	7.5	6.2	5.6	6.4	8.1	9.2	7.8	8.6	7.6	Sunlight Hours / Day (d)
7.9	0.7	0.8	0.8	0.6	0.5	0.5	0.5	0.7	0.8	0.7	0.7	0.7	Mean Monthly Temperature(C)
131.5	7.5	9.4	11.4	13.6	14.3	14.3	15.1	13.6	10.7	8.2	7.0	6.4	Heat Index (I)
8.2	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.6	0.6	0.6	Constant (a)
2,193.8	196.0	220.7	221.9	168.8	143.5	129.6	142.7	188.4	211.3	189.7	191.8	189.3	Potential Evapotranspiration (PET)
-809.5	-176.1	-216.5	-121.0	15.2	304.2	91.6	-11.9	-55.2	-160.3	-184.4	-184.8	-110.3	P - PET
-6,980.9	-513.6	-337.5	-121.0	0.0	0.0	0.0	-1,220.0	-1,208.0	-1,153.0	-993.2	-808.8	-624.0	Accumulated Potential Water Loss (APWL)
1,842.8	153.6	153.6	153.6	153.6	153.6	153.6	153.6	153.6	153.6	153.6	153.6	153.6	Available Water Capacities (AWC)
556.9	5.4	17.1	69.8	153.6	153.6	153.6	0.1	0.1	0.1	0.2	0.8	2.6	Actual Storage of Soil Moisture (STOR)
0.0	-11.6	-52.8	-83.7	0.0	0.0	153.5	0.0	0.0	-0.2	-0.6	-1.8	-2.8	Changes of Actual Storage (ΔSM)
831.5	8.3	-48.6	17.1	168.8	143.5	129.6	142.7	133.1	50.8	4.8	5.1	76.2	Actual Evapotranspiration (AET)
1,362.2	187.7	269.3	204.7	0.0	0.0	0.0	0.0	55.3	160.5	184.9	186.7	113.1	Water Deficit (DEF)
552.7	0.0	0.0	0.0	15.2	304.2	245.1	-11.9	0.0	0.0	0.0	0.0	0.0	Surplus (SUR)
1,128.3	28.6	57.2	114.3	228.6	426.8	245.1	0.0	0.9	1.8	3.6	7.1	14.3	Available Runoff (ARO)
564.2	14.3	28.6	57.2	114.3	213.4	122.6	0.0	0.4	0.9	1.8	3.6	7.1	Runoff (RO)
564.2	14.3	28.6	57.2	114.3	213.4	122.6	0.0	0.4	0.9	1.8	3.6	7.1	Detention (DET)

TABLE 3: AVERAGE ANNUAL WATER ACCUMULATION & AVAILABILITY OF SURFACE WATER

Items	Estimated Value (in Million Cubic Meter)
Average Annual Water Accumulation	1128.3
Annual Water Runoff	564.2
Annual Surface Water Availability	564.2

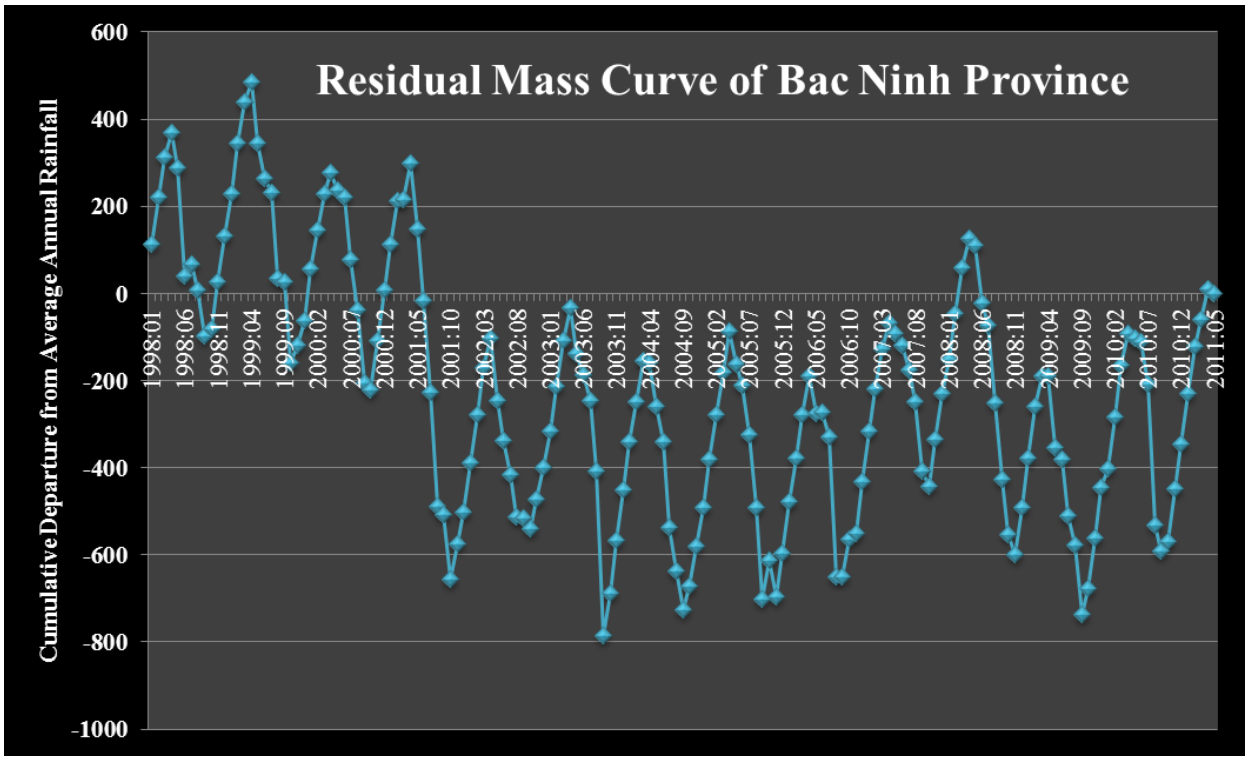

FIGURE 3: RESIDUAL MASS CURVE OF BAC NINH PROVINCE (VIET NAM)

7. ASSESSMENT OF WATER NEED FOR DRINKING AND DOMESTIC PURPOSE

Water need for drinking and other domestic purpose depends on physical as well as socio-economic level of development. However, World Health Organization has estimated this need at 200 liters per person per day in perspective of western countries. It would be very high in Viet Nam context. It is estimated that 200 liters would be sufficient for one person per day living in towns and only 70 liters per person for people living in villages not using flash latrines.

Even this qualified estimate of WHO is grossly unrealistic for a backward country like Viet Nam and its rather rural province like Bac Ninh. The reasons are following.

- **Water available on large scale in Viet Nam, but it is not used and managed properly**
- **Flush latrines are not available for a sizeable chunk of population even in cities/towns**
- **There are however no metro cities in Bac Ninh Province, which two or three are only mid-range towns/city**
- **More than 75% population of Bac Ninh is backward and living in rural area**
- **Water supply through Govt. Agency in various towns and cities in Bac Ninh Province, even quantitatively, is miserably below the WHO standards**
- **200-liter water per person per day may only be obtaining in few high officers' bungalows, or, perhaps, the cantonment areas**
- **In rural areas, without institutionalized water supply, as they mostly are, people are culling out only a few liter water per day per person**

Not surprisingly, therefore, average water consumption is found be only 100 liter per day per person in urban areas and 70 to 75 liter per day per person in rural areas. Taking this acceptable average, water for drinking and domestic purpose has been estimated on the basis of rural and urban population of 2011. Total rural population (Year 2011) of the Bac Ninh Province is 948,079 persons and urban population is 291,239 persons. Thus, the total requirement (Table 4) of rural people per annum works out at 66.37 mcm and for urban people at 29.12 mcm.

TABLE 4: BAC NINH PROVINCE: TOTAL WATER REQUIREMENTS

Total Population Year - 2011*	Population (in Bac Ninh Province)		Water Need (in MCM)		Total Water Requirements (in MCM)
	Rural Population	Urban Centers / City Population	Rural	Urban	
12,39,318	948,079	291,239	66.37	29.12	95.49

*** Total population (Year-2011) is the estimated population of year-2009, as growth of 10%**

7.1. ASSESSMENT OF WATER NEED FOR IRRIGATION PURPOSE / AGRICULTURAL USED

With the modernization of agricultural technology, irrigation has become imperative. It is necessary not only for raising output but also for stabilizing the cropping pattern. Total agricultural area is 43722.0 hectare (53.11 % of the total area) in the Bac Ninh Province (Figure 4, and Table 5). It means water resources of the province must be used for this

purpose. As a standard or/and agricultural scientist worked out irrigation nod at 1m column of water per aerial unit irrigated. Considering that irrigation is practically feasible over only half of the agricultural area due topographic and other reasons, the total annual requirement of the region can be estimated with help of this figure and the agricultural area of the province, which works out at 218.61 mcm (Table 6).

TABLE 5: BAC NINH PROVINCE - LAND USE / LAND COVER MATRIX

	Total Area (Hectare)	LAND USE AND LAND COVER					
		Agricultural Land	Water Surface	Forestry Land	Specially Used Land	Homestead Land	Un-used Land
Whole Province	82313.0	43722.0	5,071.5	619.8	16,698.5	9,914.0	636.1
Tp. Bac Ninh	8,260.9	3,336.8	362.1	213.9	2,450.0	1,436.3	56.5
Yen Phong	9,686.2	5,791.8	378.6	-	1,911.3	916.4	34.4
Que Vo	15,484.8	8,583.2	855.5	153.0	2,749.8	1,743.8	161.6
Tien Du	9,568.7	4,990.6	519.7	209.1	2,328.4	1,101.9	60.3
TX. Tu Son	6,133.2	2,952.4	206.1	1.3	1,923.9	755.8	20.8
Thuan Thanh	11,832.9	7,050.1	523.4	-	2,051.5	1,309.4	91.7
Gia Binh	10,779.8	5,499.9	896.3	42.4	1,778.6	1,311.7	152.7
Luong Tai	10,566.6	5,517.2	1,329.7	-	1,505.1	1,338.6	58.2

FIGURE 4: AERIAL VIEW (LULC) OF BAC NINH PROVINCE (VIET NAM)

TABLE 6: BAC NINH PROVINCE - TOTAL WATER REQUIREMENT FOR AGRICULTURAL PURPOSE

District / City / Town	Total Area: Bac Ninh Province (in Sq Kms)	Total Agricultural Land (Sq Kms)	Water Required to Irrigate 50% (in MCM)
Whole Province	823.130	437.220	218.61
Tp. Bac Ninh	82.609	33.368	16.68
Yen Phong	96.862	57.918	28.96
Que Vo	154.848	85.832	42.92
Tien Du	95.687	49.906	24.95
TX. Tu Son	61.332	29.524	14.76

Thuan Thanh	118.329	70.501	35.25
Gia Binh	107.798	54.999	27.50
Luong Tai	105.666	55.172	27.59

The requirement of water for different purposes (Table 7) can be aggregated as follows for presenting the holistic picture for the Bac Ninh Province.

TABLE 7: BAC NINH PROVINCE - GROSS WATER DEMAND

S. No.	Purpose	Requirement (in MCM)
1.	Drinking / Domestic	95.49
a.	Rural	66.37
b.	Urban	29.12
2.	Irrigation Purpose / Agricultural Used	218.61
3.	Industrial Used (assume 35% of domestic use)	33.42
	Gross Demand	347.52

7.2. AVAILABILITY OF SURFACE WATER FOR FUTURE INDUSTRIAL, AGRICULTURAL / IRRIGATION DEVELOPMENT

Deducing 5% as natural discharge during non-monsoon months from the annual surface water availability does the computation of potential for future irrigation. The balance surface water availability for future development in Bac Ninh Province is worked out to be 188.50 mcm (Table 8). The details of gross demand, deducing of 5% as natural discharge during non-monsoon months, and balance surface water availability for future development are shown in Figure 5.

TABLE 8: WATER BUDGET FOR BAC NINH PROVINCE

S. No.	Items	Units in MCM
1.	Annual Surface Water Availability	564.23
a.	Drinking / Domestic	95.49
b.	Irrigation Purpose / Agricultural Used	218.61
c.	Industrial Used (assume 35% of domestic use)	33.42

2.	Gross Demand	347.52
3.	Deducing 5%, as Natural Discharge during Non-Monsoon Months	28.21
4.	Balance Surface Water Availability for Future Development	188.50

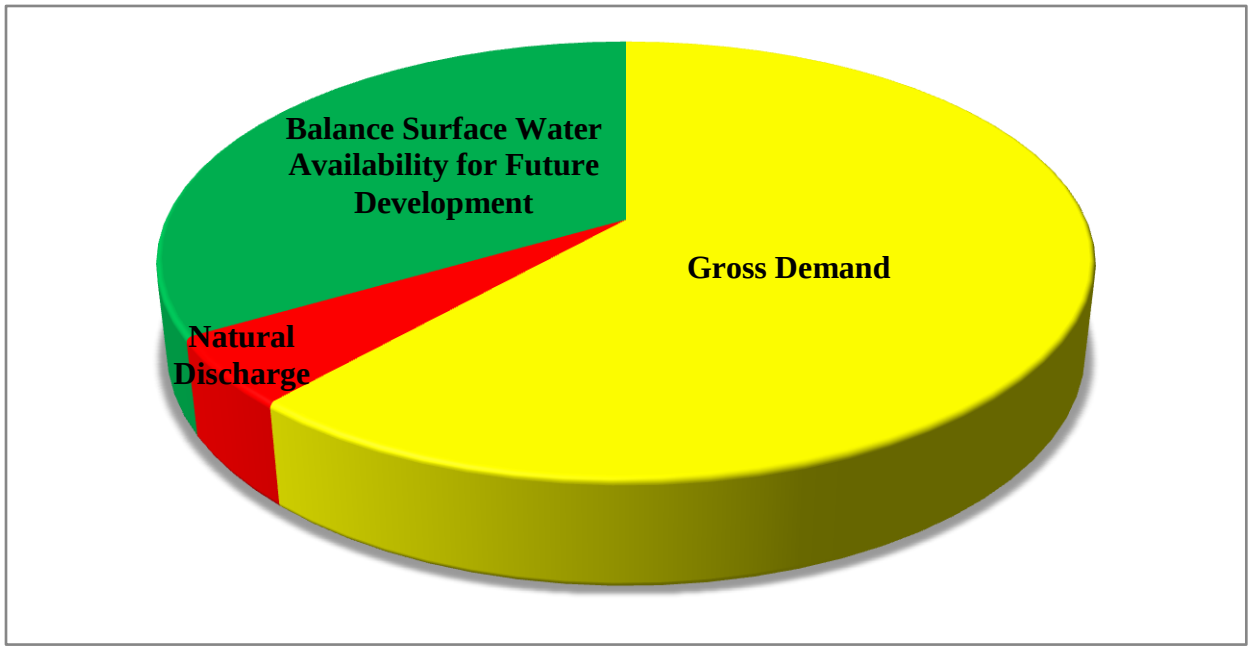

FIGURE 5: WATER BUDGET FOR BAC NINH PROVINCE

8. CONCLUSION

The water balance study using the Thornthwaite and Mather (TM) models with the help of remote sensing and GIS is very helpful in finding out the moisture deficit and moisture surplus for an entire Bac Ninh Province. The water balance calculation shows that the maximum annual runoff results from the built-up areas/water body followed by agricultural land, forest and minimum for the barren land and open forest. The annual deficit in the Bac Ninh Province is 1362.2 mcm and the annual surplus is 552.7 mcm. GIS software's have been used for spatial analysis for generation of various thematic layers and integration to produce the final runoff map. The total Available runoff and runoff of Bac Ninh Province was calculated as 1128.3 mcm & 564.2 mcm respectively from the total precipitation of 1384.2 mm (Year-2011). The annual surface water availability for Bac Ninh Province works out at 564.23 mcm. Deducing 5%, which is usually regarded as natural discharge during non-monsoon months, thus region as 536.02 mcm as surface water availability. The current gross demand as drinking & domestic, irrigation purpose / agricultural used, and industrial used is 347.52 mcm (64.83%). The balance surface water availability for future development in the Bac Ninh Province is 188.50 mcm.

Nevertheless, it will be start-range view to jump upon this course of action. In order to manage the surface water resource on a sustainable basis, care must be taken to implement the surface water augmentation structures as planned, all along the strategy surface water development.

ACKNOWLEDGEMENT

The author is grateful to Mr. Kapil Chaudhery, Director Spatial Decisions, Hanoi, Vietnam for providing the necessary facilities to carry out this work. I am also thankful to my Guru Ji Prof. J. L. Jain for the motivation of this work.

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