CHAPTER II. GEOHYDROLOGY OF THE GANGA AND BRAHMAPUTRA RIVER SYSTEMS

Miller (1961) has shown that under the same climatic conditions rocks of similar composition will weather to produce effluent waters of similar composition. Thus, under the uniform climatic conditions the variations in river water composition should reflect the influences of different rock types. In order to evaluate the river water chemistry in terms of chemical weathering of the rocks and soils of the drainage basin (the focus of this study) it is necessary to identify the regions of representative geology. Furthermore, the hydrologic response of the drainage basin is closely related to its geology. This chapter describes the geological, lithological and hydrological characteristics of the Ganga and Brahmaputra River drainage basins.

II.1. Ganga River system

The Ganga River system represents a large river catchment (Figure II-1), occupies about $10^6 \text{km}^2$ area of the Indian subcontinent (Rao, 1975). To
the north are the Himalayas and to the south are the large Indo-Gangetic alluvial plains and the Vindhyan-Bundelkhand plateau. The climate of the Ganga River basin is considered to be humid tropical type. Most of the precipitation occur during south-west monsoon (July-September).

The Ganga at its origin is known as Bhagirathi which has its source in the Gangotri Glacier at an elevation of 7000 m, in the Kumaun Himalayas. Alaknanda is the major tributary of Bhagirathi, after their confluence at Devprayag, the river acquires the name 'Ganga'. The river descends into the plains after cutting across the Siwalik range at Hardwar and flows in the south-east direction. Along the course it receives a large number of tributaries, Figure II-1. The major tributaries of the Ganga are Gomti, Ghaghara and Gandak joining from the north and Yamuna and Son from the south. The Yamuna in turn receives Chmabal, Betwa and Ken, the major tributaries joining from its right bank (Figure II-1). The Yamuna, Ghaghara and Gandak also originate in the Himalayas, after draining through the southern slopes of the Himalayas these rivers
descends into the Indo-Gangetic alluvial plains (Figure II-1). The major source of water to these rivers is the precipitation during south-west monsoon. During lean flow in summer months, the flow in these rivers is mainly sustained by snow/glacier melt waters. The Chambal, Betwa, Ken and Son originate in the Vindhyan-Bundelkhand plateau (Figure II-1). Though perennial, the peak flow in these rivers occurs during south-west monsoon (July-September). During lean flow these rivers receive considerable supply of water by effluent seepage of groundwaters. The hydrological characteristics of the Ganga and its tributaries are given in Table II-1. The total length of the Ganga from its source to its outfall into the Bay of Bengal is 2525 km. The average annual flow in the Ganga at Patna is $364 \times 10^{12}$ L/yr (Rao, 1975). The largest contribution, nearly one-fourth, is from the Ghaghara. The next large contribution is by the Yamuna, then followed by the Gandak. Nearly 60\% of the water flowing in the Ganga comes from the drainage areas north of the river (Rao, 1975).
Figure II - 1.

Map of the Ganga and Brahmaputra River systems.
Figure II - 1

GANGA-BRAHMAPUTRA RIVER SYSTEMS
Table II-1. **Hydrological Characteristics of the Rivers**

<table>
<thead>
<tr>
<th>River</th>
<th>Length (km)</th>
<th>Drainage Area (x 10^3 km^2)</th>
<th>Average Annual discharge (x 10^12 L)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ganga</td>
<td>1050</td>
<td>-</td>
<td>59</td>
<td>Ganga at Allahabad, before confluence with Yamuna</td>
</tr>
<tr>
<td>Yamuna</td>
<td>1376</td>
<td>139.5</td>
<td>93</td>
<td>Yamuna at Allahabad, before confluence with Ganga</td>
</tr>
<tr>
<td>Chambal</td>
<td>965</td>
<td>-</td>
<td>30</td>
<td>Tributary of Yamuna</td>
</tr>
<tr>
<td>Betwa</td>
<td>590</td>
<td>45.6</td>
<td>10</td>
<td>Tributary of Yamuna</td>
</tr>
<tr>
<td>Ken</td>
<td>360</td>
<td>28.2</td>
<td>11</td>
<td>Tributary of Yamuna</td>
</tr>
<tr>
<td>Gomti</td>
<td>940</td>
<td>30.4</td>
<td>7.5</td>
<td>Tributary of Ganga</td>
</tr>
<tr>
<td>Ghaghara</td>
<td>1080</td>
<td>128</td>
<td>94</td>
<td>Tributary of Ganga</td>
</tr>
<tr>
<td>Son</td>
<td>784</td>
<td>71.3</td>
<td>32</td>
<td>Tributary of Ganga</td>
</tr>
</tbody>
</table>
Table II-1. Contd.

<table>
<thead>
<tr>
<th>River</th>
<th>Length *1 (km)</th>
<th>Drainage *1 Area (x 10^3 km^2)</th>
<th>Average *1 Annual discharge (x 10^{12} L)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gandak</td>
<td>-</td>
<td>46.3</td>
<td>52</td>
<td>Tributary of Ganga</td>
</tr>
<tr>
<td>Ganga *2</td>
<td>1600</td>
<td>861</td>
<td>364</td>
<td>Ganga at Patna, after confluence of Ghaghara, Son and Gandak</td>
</tr>
<tr>
<td>Manas</td>
<td>-</td>
<td>37.5</td>
<td>-</td>
<td>Tributary of Brahmaputra</td>
</tr>
<tr>
<td>Brahmaputra *3</td>
<td>2400</td>
<td>(187)</td>
<td>510</td>
<td>Brahmaputra near Goalpara, after confluence with Manas</td>
</tr>
</tbody>
</table>

*1. From Rao (1975)

*2. The total length, drainage area and average annual discharge of Ganga is 2525 km, 970x10^3 km^2, and 460x10^{12} L respectively.

*3. The total length and drainage area of Brahmaputra is 2900 km and 580x10^3 km^2 respectively, number in parentheses indicates the drainage area in India.
Figure II - 2.

Geologic and lithologic map of the Ganga and Brahmaputra River drainage basins (Reproduced from Singh, 1971).
Figure II-2. Symbol Key

- Pleistocene, Younger and Older alluvium.
- Siwalik, Coarsely-bedded sandstones, sandrocks, clays, conglomerates.
- Gondwana and Upper Paleozoic
- Lower Paleozoic: Paleozoic to Mesozoic sedimentary rocks: mostly sandstones, shales, carbonates.
- Mesozoic
- Mesozoic and Paleozoic windows
- Vindhyan and Cuddapah system
- Dharwar system: Precambrian metamorphic rocks: mostly high grade gneisses, schists, quartzites and metamorphosed limestones.
- Unclassified crystallines
- Granites, Intrusive, igneous rocks of all ages.
- Malani volcanics: Extrusive igneous rocks ranging from Acid to Basic types with intertrapped sedimentary rocks like sandstones and shales.
- Rajmahal and Deccan flows
The drainage basin of Ganga (Figure II-1) lies within three major physiographic zones, the Kumaun Himalayas, the Indo-Gangetic alluvial plains and the Vindhyan-Bundelkhand plateau. These three zones are characterised by distinct geology (Figure II-2) soils, relief and to some degree climate and vegetation. The Kumaun Himalayas are subdivided into three broad stratigraphical zones (Gansser, 1964; Valdiya, 1980; Wadia, 1981):

(i) The Outer or Sub-Himalayan zone, composed of sediments mostly of Tertiary age. The foot-hill belt of this region is built entirely of Siwalik sediments. The Siwaliks constitute a great thickness of detrital rocks such as coarsely-bedded sandstones, sand-rocks, clays and conglomerates. Siwaliks are subdivided in three stratigraphic units: Lower, Middle and Upper Siwaliks. The composition and characteristics of the Siwalik strata bear evidence of their
very rapid deposition by the rejuvenated Himalayan rivers.

(ii) The Central or Lower Himalayan zone, the main structural features of this zone are: (a) the outer Krol belt of upper Carboniferous age, consisting mainly of dolomitic-limestones, calcareous shales and sand-stones. Gypsum occurs in large masses replacing Carboniferous limestones, (b) the inner sedimentary belt (Deoban-Tejam zone) which stretches across the Bhagirathi and the Alakananda River basins. The major feature of its stratigraphy is the occurrence of lower Paleozoic carbonate series of enormously thick limestones and dolomites overlain by a sequence of shales and quartzites. The inner sedimentary zone is separated from the outer Krol belt by the Almora-Dudatoli thrust sheet which is a huge crystalline mass of metamorphic rocks.
(iii) The Higher Himalayan zone, the main rocks of this zone are quartzites, migmatites, gneisses, garnet-schists and dioritic amphibolites.

The Indo-Gangetic alluvial plains are formed by pre-Tertiary river-borne debris from the Indian Peninsula and post-Tertiary Himalayan debris brought by the present day major rivers, viz, Ganga, Yamuna, Ghaghara and Gandak. The area of these alluvial plains is about $7 \times 10^5 \text{km}^2$ (Wadia, 1981). The recent calculations from geodetic surveys estimate a thickness of more than 5000 m for these alluvial deposits resting on the pre-Tertiary bed rocks. The rocks are everywhere of fluviatile and sub-aerial formation - massive beds of clay, either sandy or calcareous, corresponding to the silts, mud and sand of the Himalayan rivers. A characteristic of the clayey part of the alluvial plains, particularly in the post-Tertiary deposits, is the abundant dissemination of impure calcareous matter in the form of irregular "Kankar". The formation of Kankar concretions is due to the segregation of the calcareous material of the alluvial deposits into lumps.
or nodules. The alluvium of some places contains as much as 30 percent calcareous matter (Wadia, 1981).

A large part of the alluvial soils in the drier regions of the Indo-Gangetic alluvial plains is impregnated with alkaline and saline salts (Figure II-3). The characteristics and genesis of these alkaline and saline soils occupying the micro-depressions in the alluvial plains have been described by several workers (Abrol and Bhumbla, 1971, 1978; Raychaudhuri and Govindarajan, 1971; Bhargava et al, 1980, 1981). Numerous torrents and seasonal streams originating in the Siwaliks debouch into the plains bringing in large quantities of runoff. Despite the perennial rivers, viz, the Ganga and the Yamuna, the Indo-Gangetic alluvial plain broadly constitutes an endoric inland area lacking a well-developed natural surface-drainage network (Wadia, 1981). In such circumstances the surface runoff laden with the weathering products (chiefly bicarbonates and carbonates of alkali and alkaline earths) brought by the Siwalik streams
Figure II - 3.

Salt affected soils in the Ganga River drainage basin, adopted from the map published by CSSRI, Karnal, 1975.
cause intermittent flooding of the micro-depressions. In many parts of the hot alluvial plains, which have got no underground drainage of water, the bulk of the accumulated runoff is lost only through evaporation. Thus, the accumulation of the weathering products in the low-lying areas during the rainy season, evaporation in the post-monsoon months and the repetition of these flooding and evaporation cycles, appear to be the main factors that have resulted in the formation of these alkaline and saline salt-affected soils. Calcium and magnesium are the first to get precipitated as carbonates as the process of evaporation occurs and the soil solution gets increasingly concentrated with sodium. The lime concretions of finer sizes distributed in the upper 1 m depth result from this kind of pedogenic release of calcium and magnesium (Bhargava et al, 1981). Alkaline soils are concentrated in the zone of mean annual rainfall ranging from 50 to 100 cm (Bhargava et al, 1980). These soils are characterised by the dominance of sodium bicarbonate and carbonate among the soluble salts. In contrast, the saline soils tend
to occur in regions with an annual rainfall of less than 50 cm, sodium chloride and sulfate are the main salt types. Groundwaters in these areas serve as the main source of soil salinization (Bhargava et al, 1980).

The headwaters of the Chambal, Betwa and Ken Rivers originate in the Vindhyan-Bundelkhand plateau. Geologically the region forms a part of the Archaean shield of the Deccan Peninsula. The main geological systems representative of this region are (Wadia, 1981):

(i) The Archaean System, represented by 'massif Bundelkhand' which is largely composed of crystalline igneous and metamorphic rocks. Based on their texture and composition, several types of granites can be recognised in Bundelkhand.

(ii) Transitional System having been formed in the post-Aravalli or pre-Vindhyan period. The system represents sedimentary strata of sandstones and limestones in which lava intrusions had later penetrated. It also
represent a contorted arrangement of very hard and soft rocks that are chiefly composed of massive quartzite sandstones and granitic sandstones.

(iii) The Vindhyan System forms a series of escarpments of massive sandstones and limestones which were originally deposited in a shallow but extensive basin.

(iv) Recent Deposits, which are represented by large scale alluvial deposits. The alluvial sediments are of fluviatile and subaerial formations of sand, silt and clay.

The lower Vindhyans of the Son River Valley are largely composed of limestones, shales and sandstones with interbedded porcellanites (silicified ash). The shales are sparsely developed and are of local occurrence only. They are often carbonaceous, siliceous or calcareous.

II. 2. Brahmaputra River

Brahmaputra rises in Chamyungdung Glacier in the Tibetan Himalayas, at an elevation of 5200 m. After
flowing parallel to the main Himalayan Range it enters the Assam Valley. A number of small tributaries join the main river in Assam from the north and south. The hydrological characteristics of the Brahmaputra River are given in Table II-1. Ganga and Brahmaputra merge with each other in Bangladesh and subsequently break into a number of estuaries before their outfall into the Bay of Bengal (Figure II-1).

The geological information on the Tibetan Himalayas is very restricted, vague and limited to its outermost part. The lithology, of the southern slopes of the Tibetan Himalayas along the course of Brahmaputra River, is dominated by reduced shales, gneisses and volcanic rocks. Reduced shales, gneisses and granites are notably potassic (Gansser, 1964). The river drainage basin in the Assam Valley consists of recent and Pleistocene alluvium. In the middle part of the Valley, the river encounters the granite and gneiss projections of the Mikir Hills.