2. THE STUDY AREA

2.1 Location and Accessibility

Muzaffarnagar is an important district in Western Uttar Pradesh and the town Muzaffarnagar is the district Headquarter. It lies in the interfluves of Ganga and Yamuna rivers in the western most part of the Uttar Pradesh state of India.

District Muzaffarnagar boasted one of the highest per capita income in the country and the highest in the state of Uttar Pradesh. The Jaggery market in Muzaffarnagar is largest in the world. The prosperity of area lies in the fact that it has got excellent fertile track and is famous for sugarcane cultivation. Rapid industrialization in the form of Sugar, Steel and Paper industries is observed (http://en.wikipedia.org/wiki/Muzaffarnagar).

The study area falls between Longitudes 77°05′ and 77°27′ E and latitude 29°15′ and 29°41′ N (Fig.2.1) and covers an area about 1100 km². The Rivers Yamuna and Krishni forms the western and eastern boundaries, respectively. It is well connected with adjoining town such as Saharanpur and Meerut by rail and roads. Almost all the villages of the area are approachable by motorable roads.

2.2 Climate

The climate of the area is characterized by general dryness except during the brief span of monsoon season. It has a hot summer and a cold winter. The year is divided into the four seasons. The period from the middle of November to about the ends of February is the cold season. The hot season which follows, continues up to the end of June. The rainy season spans over the period of mid June to September. The post-monsoon or the pre-winter extending from mid September to mid November follows this. The highest temperature, reaching to 45°C is generally recorded during the month of June. The lowest temperature of about 4°C is recorded during the month of January. The average mean daily temperature of the area ranges from 20°C to 32°C.

Winds are generally light and only a little strong in the summer and monsoon seasons. During October and April, they are mostly westerly or northwesterly. From May, they become easterly and during the southwest monsoon season, they are predominantly easterly or southeasterly.
Fig. 2.1 Location map of the study area
2.3 Physiography and Drainage

The district Muzaffarnagar is rectangular in shape and lies between latitude 29°11' N and 29°43' N and longitude 77° 04' E and 78°07' E. It is situated between the districts of Saharanpur on the north, Meerut and Baghpat on the south and is bounded by the Ganga on the east and the Yamuna on the west. The main rivers, the Ganga, the Kali, the Hindon, the Krishni and the Yamuna have played an important role in carving the topography of the district and divide it four fairly distinct physiographic units (Khan 1992) i.e. the (i) Ganga Khadir (Newer alluvium), (ii) upland up to Kali River (iii) the Kali-Hindon interfluve and the (iv) Hindon-Yamuna interfluve. The study area, Yamuna-Krishni sub basin is a part of Hindon-Yamuna interfluve.

The river Yamuna forms the western boundary of the district, flows in an irregular course from north to south with uncertain and not well defined channels. The river commands a large tract of low lying area of newer alluvium which is locally known as Khadir. The Khadir of the Yamuna is much better cultivated, Kharif and Zaid cropping is much in practice in this area. The river Krishni forms the eastern boundary of the area. Near the river Krishni there is poor soil and low land areas which are well adapted for rice cultivation. Krishni flows in a well defined channel, and the Khadir is small as compared to Yamuna.

Beyond the Krishni river lies a good tract of land traversed by the main channel of the Eastern Yamuna canal. The central region and area due south from Shamli have got excellent fertile soil and therefore this region is densely cultivated. However, north of Shamli, the tract is poorly cultivated. The low grounds along the canal have got saline soil which is locally known as Reh, has thrown considerable area out of cultivation. Generally speaking, the soil is much less sandy than in and around the Eastern Yamuna Canal tract.

The area exhibits a gentle slope due south and southwest where the elevation ranges between 262 metres near village Chandelmal in north to 224 m in the south at village Issapurteel. The area between Katha drain and Eastern Yamuna Canal is central upland region which has elevation from 245-240 metres amsl. The central upland region is very fertile but the groundwater level is very deep. The Main canal i.e. the Eastern Yamuna Canal enters from north, near village Bhanera Uda and traverse through the area in north south direction. The eastern and western portions of the central high land slope down towards the rivers on either side, and are marked by ravines which cut into the good land above.
The drainage of the study area is mainly controlled by the two rivers i.e. Krishni and Yamuna, which are flowing from north to south. Both the rivers are perennial and meandering in nature. Katha and Khokharni drains are small, left over channels of river Yamuna, which flow along the NW side of the area and join the Yamuna river near village Mawi and Kertu, respectively.

2.4 Digital Elevation Model

A digital elevation model (DEM) is a digital representation of ground surface topography of terrain. It is also widely known as digital terrain model (DTM). The DEM often comprises much of the raw dataset, which may have been acquired through techniques such as photogrammetry, LiDAR, IfSAR, land surveying etc. A DTM on the other hand is (generally) a filtered version of DEM. A DEM can be represented as a raster (a grid of squares) or as an triangular irregular network. The DTM provides a bare earth model, devoid of landscapes features. While a DEM may be useful for landscape modeling, city modeling and visualization application (http://en.wikipedia.org/wiki/Digital_elevation_model).

Digital elevation model consists of raster grid of regularly spaced elevation values produced by USGS. A much higher quality DEM from the Shuttle Radar Topography Mission (SRTM) is also freely available for most of the globe and represents elevation at a 3 arc-second resolution (around 30 m) (http://edc.usgs.gov/products/elevation/dem.html).

The quality of a DEM is a measure of how accurate elevation is at each pixel (absolute accuracy) and how accurately is the morphology presented (relative accuracy). Several factors play an important role for quality of DEM-derived products:

- Terrain roughness
- Sampling density (elevation data collection method)
- Grid resolution or pixel size
- Interpolation algorithm
- Vertical resolution
- Terrain analysis algorithms

Common uses of DEM includes

- Extracting terrain parameters
- Modeling water flow or mass movement
- Creation of relief maps
- Rendering of 3D visualization
- Creation of physical models (including raised relief maps)
- Rectification of aerial photography or satellite imagery
Fig. 2.2 Digital Elevation Model of Yamuna-Krishni sub basin.
Terrain analysis in geomorphological and physical geography

The topography of the sub-basin is based on Digital Elevation Model obtained with the help of SRTM data which is available at number of USGS websites (Fig. 2.2). The coordinates of the study area were overlaid over the SRTM data and the Digital Elevation Model was prepared for the boundary assigned to the software. The perusal of DEM shows that altitude varies from 262-224 metres above mean sea level (m amsl). The extreme north east part of the area has maximum elevation ranging from 262-254. In general, the central track has got higher elevations which gently slope towards the rivers courses due west and east i.e. towards the river Yamuna and Krishni, respectively. River courses have lowest elevation comparing to the adjacent area. The Krishni river has elevation of 256 m amsl at the point where it enters in to the study area and 223 where it leaves the area at the bottom. The Yamuna river elevation from top to bottom ranges from 246 to 222 m amsl, respectively. The low elevation area in the vicinity of river Yamuna is characterized by flood plains.

In the middle of upper half of the study area, tracks of Katha drain, a left channel of river Yamuna is clearly visible because of less elevation than the adjacent area. The Katha drain finally joins the Yamuna river at the middle reaches near village mawi.

2.5 Land Use/Land cover

A Landuse/Landcover (LULC) map for 1971 has been derived from Survey of India toposheets No. 53G/2, 53G/3, 53G/6 & 53G/7 on 1:50,000 scale (Fig. 2.3a). The area has been categorized into five landuse classes. It includes settlement, water body, Agricultural land, waste land and plantation. The area covered by these classes is tabulated in Table 2.1.

Another LULC map (Fig. 2.3b) was prepared using remote sensing IRS-1D Liss-III data (Path-Row 95-50) of 15 march 2002 of band combination 2 (green), 3 (red), and 4 (near infra-red), procured from National Remote Sensing Agency, Hyderabad, India. Standard visual image interpretation technique was used. Similar LULC classes were used in both time periods. Field verification of map generated was also carried out. The data obtained is listed in Table 2.1.

A change detection analysis was attempted using two time periods. The available data reveals that the area under cultivation has marginally decreased from 90.41% to 88.36% during the period from 1971 to 2002. The area covered by wasteland during 1971 was 6.6% which has reduced to 1.5% in year 2002. It shows that some of the land is reclaimed for agricultural uses. The area occupied by settlements has increased from 2.24% to 8.73%. The same period has witnessed
Fig. 2.3a Landuse/Landcover pattern in the study area (1971).
Figure 2.3b Landuse/Landcover pattern in the study area (2002)
doubling of population from 1.8 to 3.54 million. These figures clearly indicate the alarming level of threat to the groundwater system of the area.

Table 2.1 Showing change in Landuse/Landcover pattern in the study area

<table>
<thead>
<tr>
<th>S.No.</th>
<th>LULC Class</th>
<th>Area (sq. km.)</th>
<th>% Coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Settlement</td>
<td>24.67</td>
<td>96.08</td>
</tr>
<tr>
<td>2</td>
<td>Water Body</td>
<td>1.93</td>
<td>1.34</td>
</tr>
<tr>
<td>3</td>
<td>Agricultural Land</td>
<td>994.95</td>
<td>972.4</td>
</tr>
<tr>
<td>4</td>
<td>Wasteland</td>
<td>72.66</td>
<td>16.47</td>
</tr>
<tr>
<td>5</td>
<td>Plantation</td>
<td>6.3</td>
<td>14.22</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>1100.51</td>
<td>1100.51</td>
</tr>
</tbody>
</table>

2.6 Water Utilization Pattern

The area has got excellent fertile tracks and annually three crops system is in practice. Sugar cane and Wheat are the main crops. Groundwater is the major source of irrigation. Surface water also contributes partially to irrigation in canal command area.

Out of total water resources of the Yamuna-Krishni sub-basin, only 8.1% is derived from the surface water sources and 91.9% from the groundwater (Fig.2.4a). The Eastern Yamuna Canal and its distributaries are main source of surface water irrigation.

The block wise water utilization pattern is shown in figure 2.4b. A perusal of figure shows that the blocks traversed by Eastern Yamuna Canal have maximum surface water utilization which range from 9 to 13% of total water use. In the rest of the blocks contribution from surface water is, on an average, is less than 5%. These figures clearly show stress on groundwater regime of the area.

![Water utilization pattern](image)
Fig. 2.4b Block-wise water utilization pattern
2.7 Rainfall and its Temporal Variability

The monsoon season starts in the second week of June. Heavy precipitation, however, takes place in the months of July and August and monsoon finally retreats by the end of September every year. The available annual rainfall data of Kairana and Shamli for the period of 1968-2007 and 1994-2007 have been statistically analysed and results are tabulated in Table 2.2 & 2.3, respectively. It is observed that the highest rainfall at Kairana rain gauge station is 1388 mm in the year 1978 whereas the lowest 202.3 mm (1975) showing a very wide range of variation. The mean annual rainfall is 703.15 mm. The highest rainfall at Shamli rain gauge is 1099.2 mm in the year 1995 whereas the lowest is 206 mm in the year 1993 showing a wide range of variation. The mean annual rainfall is 697.2 mm. The results of Statistical analysis of rainfall data at Kairana and Shamli Rain gauge Station is given in Appendix-IIA and IIB. The yearly rainfall distribution is shown in figure 2.5a and 2.5b.

2.7.1 Spatial Distribution of Rainfall

An isohyetal map using an average rainfall of 11 years period (1997-2007) for 5 rain gauge station was prepared for district Muzaffarnagar. A perusal of isohyetal map (Fig.2.6) shows that intensity of rainfall decreases from east to west. A minimum of less than 500 mm of rainfall is received in south-western part which gradually increases to more than 1200 mm due east, proximal to river Ganga.

![Fig.2.5a Yearly rainfall at Kairana Rainguage (1968-2007).](image)
Shamli Rain gauge Station

Fig. 2.5b Yearly rainfall at Shamli Rain gauge (1990-2007).

Table 2.2 Results of statistical analysis of annual rainfall at Kairana Rain gauge Station.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Highest Rainfall (1978)</td>
<td>1388 mm</td>
</tr>
<tr>
<td>Lowest Rainfall (1975)</td>
<td>202 mm</td>
</tr>
<tr>
<td>Mean</td>
<td>703 mm</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>252</td>
</tr>
<tr>
<td>Coefficient of variation</td>
<td>35.49%</td>
</tr>
</tbody>
</table>

Table 2.3. Results of statistical analysis of annual rainfall at Shamli Rain gauge Station.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Highest Rainfall (1995)</td>
<td>1099 mm</td>
</tr>
<tr>
<td>Lowest Rainfall (1993)</td>
<td>206 mm</td>
</tr>
<tr>
<td>Mean</td>
<td>697 mm</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>303</td>
</tr>
<tr>
<td>Coefficient of variation</td>
<td>43.5 %</td>
</tr>
</tbody>
</table>
Fig. 2.6 Isohyetal map showing distribution of average annual rainfall.
2.8 Soil Types

The Indo-Gangetic Plains are formed by the periodic deposition of silt brought by rivers abounds in alluvial soil. The alluvial tracks of Ganga-Yamuna interfluve have got very fertile soil. The study area is characterized by three types of soils viz. (i) Loam (ii) Clay Loam and (iii) Sandy Loam (Survey of India 2003). The distribution of the three soil types is shown in figure 2.7

2.8.1 Loam Soil

This type of soil is found in an elongated track between Eastern Yamuna Canal and river Krishni. This track is having excellent cultivation. This is the most common type of soil in the area. Generally, the surface soil to a depth of 20-25 cm is well drained soil and contains loose loam that can easily be ploughed and cultivated. The soils are more leached than the other soil of the area. The percentage of lime content is low. The calcareous nodules occur almost everywhere in the sub-soil. The pH ranges between 6.2 to 6.8.

2.8.2 Clay Loam Soil

Clay loam soil has striking geographical attributes as it occurs all along the Yamuna river. Towards the east it occurs between Eastern Yamuna Canal and Krishni river but confined to the northern part of the study area. The tract is underlain by thick pan of calc concretions occurring in mild cases in the form of nodules which at places cement together forming a stiff impermeable belt in the bottom layers. Due to poor drainage, the soluble sodium salts are deposited on the surface in the form of salt efflorescence (salt peter) which is locally known as Reh. The pH value of the soil ranges from 7 to 9.

2.8.3 Sandy Loam Soil

This type of soil is found in a narrow elongated tract, along with the Katha drain, a left over channel of Yamuna river. This extends up to river Yamuna in the south. Generally, the soils are alkaline in reaction with a pH value above 8. The soil profile consists of numerous immature stratified layers of younger soils which are deposited over one another during the flood periods of river Yamuna. These soils have fewer reserves of lime, magnesia and iron. The presence of lime saves the soil from becoming completely salinized.
Fig. 2.7 Soil map of the study area
The study area forms a part of the Ganga basin, which is one of the physiographic units of India. The Ganga plain occupies the central position in the Indo-Gangetic foreland system. Geographically, it extends from the Aravalli-Delhi ridge in the west to the Rajmahal hills in the east, and from Himalayan foothills in the north to the Bundelkhand-Vindhyan Plateau in the south. The east-west length of the Ganga plain is about 1000 km and the north-south width varies from 450 km (western part) to 200 km (eastern part) and occupies an area of about 250,000 km² (Singh 1996, 2004). Morphologically, the Ganga plain is a shallow, asymmetrical depression with a gentle easterly slope. Along the piedmont zone, close to Himalaya, the altitude varies from 280 m in the west to 67 m in the east. Stratigraphically, it is built up of alternate layers of gravel, sand and clays of quaternary age. The Ganga plain exhibits asymmetrical sedimentary wedge, only few tens of meter thick towards peninsular craton and upto 5 km thick near Himalayan orogen (Singh 2004).

The flexing lithosphere below the Ganga plain shows many inhomogenities in the form of ridges and basement faults (Sastri 1971, Rao 1973) which are as follows

- Monghyr-Saharsa Ridge
- East Uttar Pradesh shelf
- Gandak Depression
- Faizabad Ridge
- West Uttar Pradesh Shelf
- Kasganj-Tanakpur Spur
- Ram Ganga Depression
- Delhi-Hardwar Ridge

These basement highs and faults have controlled the thickness of the alluvial fill (Bajpai 1989, Singh 1996) and have also affected the river channel on the surface.

The study area is at the fringe of Delhi-Hardwar Ridge, which represents a north-northeastward extension of the Delhi folded belt. The western limit of the Ganga basin is delimited by the Delhi-Hardwar Ridge and the oldest sedimentary sequence in the basin, namely, Upper Vindhyan, gradually thin out towards this ridge.
2.9.1 Geology

An extensive sub-surface data down to 450 m bgl have been generated under the Upper Yamuna projects of Central Ground Water Board (CGWB) with the objective of delineating the various aquifer system and their hydraulic parameters (Bhatnagar et al., 1982). On the basis of correlation of lithologs and electrical logs, four distinct groups of permeable granular zones (sand and gravel) were identified which are separated by three impermeable clay horizons. A map of the Ganga Plain showing sub-surface basement high and thickness of the foreland sediment is published by Singh 2004. This map shows that the study area lies between the contour of 1.5 and 1.0 km (Fig.2.8). Therefore the probable thickness of alluvium in the area is approximately 1.3 km.

Table 2.4 Probable Geological Succession of the study area.

<table>
<thead>
<tr>
<th>Era</th>
<th>Lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quaternary</td>
<td>Alternate bed of sand and clay with occasional beds of calcrete.</td>
</tr>
<tr>
<td>Upper Proterozoic</td>
<td>Vindhyan Super Group</td>
</tr>
<tr>
<td>Middle Protoerozoic</td>
<td>Delhi Super Group</td>
</tr>
<tr>
<td>Archean to Bundelkhand Granitoids</td>
<td></td>
</tr>
</tbody>
</table>

It appears from the above sequence that the area is underlain by the Bundelkhand Granitoids which form the Basement Complex. It appears that a very long period of erosion preceded the deposition of the Delhi group of rocks on the eroded and upturned surface of the Bundelkhand Granitoids.
2.10 Summary

The study area is a part of the Ganga Plain which is one of the physiographic units of India. The rivers Yamuna and Krishni form the western and eastern boundaries, respectively.

A DEM reveals that the area exhibits a gentle slope due south and southwest where the elevation ranges from 262-224 metres above mean sea level (m amsl). A comparison of two time (1971 and 2002) Landuse/Landcover (LULC) study shows that the area occupied by settlements has increased from 2.24% to 8.73%. The same period has witnessed doubling of population from 1.8 to 3.54 million. The figures emerge out from LULC study, clearly indicate the alarming level of threat to the groundwater system of the area.

Out of total water resources of the Yamuna-Krishni sub-basin, only 8% is derived from the surface water source and 92% are derived from the groundwater resource. The block traversed by Eastern Yamuna Canal and its distributaries utilizes up to 13% of surface water.
The area, on an average (1997-2007) receives 600 mm and 642 mm of annual rainfall at Kairana and Shamli rainguage station, respectively. The intensity of rainfall increases from west to east in Muzaffarnagar district.

The study area is characterized by three type of soil i.e. loam, sandy loam and clay loam. The clay loam soil occurs along the river Yamuna course. Loam soil occupies most of excellent cultivated tracks.

Geologically, the area is characterized by thick pile of Quaternary alluvium (>1000 m) which rest unconformably over a basement comprising quartzite of the Delhi Supar Group.