# FRAMEWORK FOR SELECTION WATERSHEDS

A watershed is an area of land that drains all the streams and rainfall to a common outlet such as the outflow of a reservoir, mouth of a bay, or any point along a stream channel. Watersheds can be as small as a footprint or large enough to encompass all the land that drains water. (Water Science School, 2019)

The word "watershed" is sometimes used interchangeably with drainage basin or catchment. Both river basins and watersheds are areas of land that drain to a particular water body, such as a lake, stream, river or estuary. In a river basin, all the water drains to a large river. The term watershed is used to describe a smaller area of land that drains to a smaller stream, lake or wetland. There are many smaller watersheds within a river basin (RIVERKEEPER, 2021).Ridges and hills that separate two watersheds are called the drainage divide. The watershed consists of surface water--lakes, streams, reservoirs, and wetlands--and all the underlying groundwater. (Water Science School, 2019)

Larger watersheds contain many smaller watersheds. It all depends on the **outflow point**; all of the land that drains water to the outflow point is the watershed for that outflow location. (Water Science School, 2019)Watersheds are important because the streamflow and the water quality of a river are affected by things, human-induced or not, happening in the land area "above" the river-outflow point. (Water Science School, 2019)

## 1 CLASSIFICATION OF WATERSHED

A watershed area can be classified based upon size, drainage, shape of area and land use pattern. (Life, 2020). If we consider the size only the watershed can be classified from the mini watershed to region.

| Sr. No. | Watershed Class | Size in ha |
|---|---|---|
| 1 | Region | >30 M |
| 2 | Basin | 3 – 30 M |
| 3 | Catchment | 1 – 3 M |
| 4 | Sub Catchment | 0.2 – 1 M |
| 5 | Watershed | 50 – 200 K |
| 6 | Sub Watershed | 10 – 50 K |
| 7 | Milli Watershed | 1 – 10 K |
| 8 | Micro Watershed | 0.1 – 1 K |
| 9 | Mini Watershed | 1 – 100 ha |

Similarly based on shape watershed can be defined as Fan and Fern shape, and based on Landuse it can be classified as highlands, tribal, urban, forest and desert watershed.

## 2 FACTOR INFLUENCING THE WATERSHED

Climate, Geology, hydrology, soil, landuse/landcover, and topography are the major factor influence the watershed and the flow of water in the watershed. Few of the factor influencing the flow of water within the watershed are as follow.

**Precipitation:** The amount of precipitation play one of major role in controlling stream flow within the watershed. But it is not necessary that all precipitation that falls in a watershed flows out.

**Infiltration**: Some of the water of the rain falls soaks in the dry ground, or infiltrates to the soil. Some of the water that infiltrate will remain in the shallow soil layer. From there either it gradually moves downhill through the soil and enter into the stream or it go further deep into the soil and eventually recharge ground water. Water may travel long distances or remain in storage for long periods before returning to the surface. The amount of water that will soak in overtime depends on several characteristics of the watershed:

> **Soil characteristics**: Clayey and rocky soils absorb less water at a slower rate than sandy soils. Soils absorbing less water results in more runoff overland into streams.
>
> **Soil saturation**: Like a wet sponge, soil already saturated from previous rainfall can't absorb much more, thus more rainfall will become surface runoff.
>
> **Geology:** Geology also play an important role of infiltration. If the area is of limestone or dolomite that have opening where water dissolve into the rock along cracks and routes to water table very quickly.
>
> **Land cover**: Some land covers/ landuse have a great impact on infiltration and rainfall runoff. Impervious surfaces, such as parking lots, roads, and developments, act as a "fast lane" for rainfall - right into storm drains that drain directly into streams. Flooding becomes more prevalent as the area of impervious surfaces increase.
>
> **Slope of the land**: Water falling on steeply-sloped land runs off more quickly than water falling on flat land.

**Evaporation**: Water from rainfall returns to the atmosphere largely through evaporation. The amount of evaporation depends on temperature, solar radiation, wind, atmospheric pressure, and other factors.

**Vegetation**: Vegetation slows runoff and allows water to seep into the ground. Also the water infiltrate into the ground are absorbed by plants through their roots in various amounts. Most of this water moves through the plant and escapes into the atmosphere through the leaves. Transpiration is controlled by the same factors as evaporation, and by the characteristics and density of the vegetation.

**Storage**: Reservoirs store water and increase the amount of water that evaporates and infiltrates. The storage and release of water in reservoirs can have a significant effect on the streamflow patterns of the river below the dam.

**Water use by people**: Uses of a stream might range from a few homeowners and businesses pumping small amounts of water to irrigate their lawns to large amounts of water withdrawals for irrigation, industries, mining, and to supply populations with drinking water.

# 3 WATERSHED DELINEATION

For watershed delineation, we need to follow following steps, as shown in Figure 1

1. Download DEM either SRTM(30) or ALSO PALSER RTC (10m)
2. Make correction in the DEM like Fill Pit and Fill Sink
3. Determine the flow direction raster
4. Make correction again in Sink and Fill until you have a depression less DEM
5. Burn already available the available stream network.
6. Add a Pour Point
7. Delineate watershed based on the pour point in the raster form
8. Calculate the flow Accumulation
9. Extract streams from the flow accumulation raster
10. Convert watershed raster to Polygon / vector data

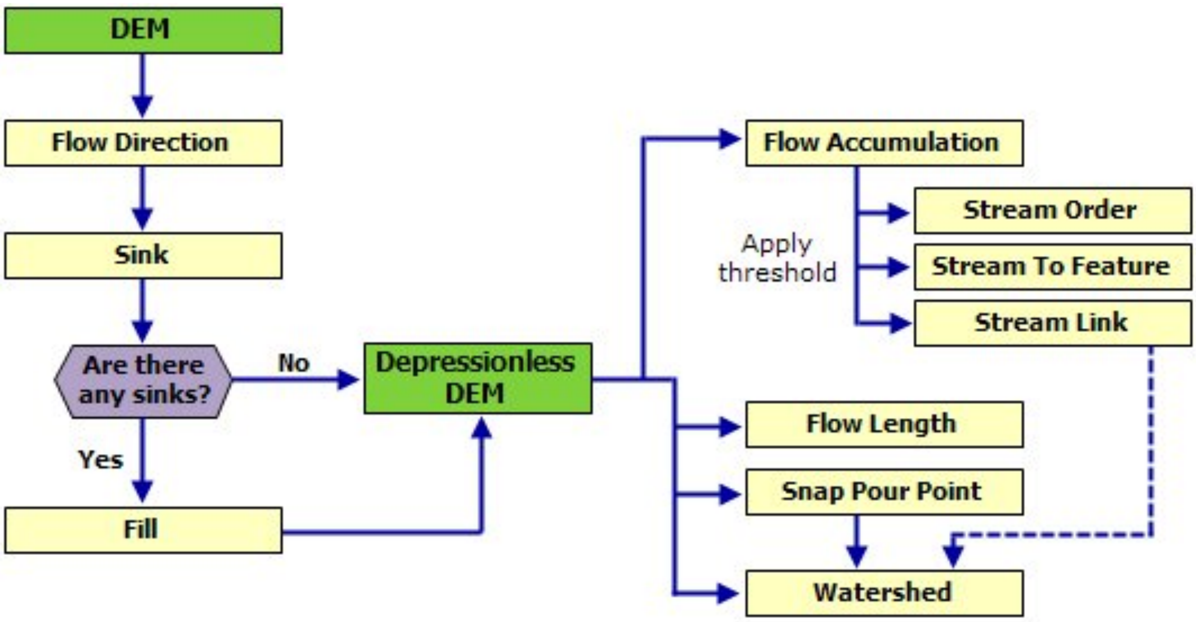


FIGURE 1: WATERSHED DELINEATION FLOWCHART

# 4 PRIORITIZATION OR SELECTION OF WATERSHED

Prioritization and selection of watershed depend on number of physical and socio-economic parameters. As multiple factors affecting the shape and flow within the watershed (as mentioned above), It is recommended to use multiple criteria analysis for decision making (MCDM). In pervious study the Food and Agriculture Organization (FAO) used following criteria, shown in table

| CRITERIA | INDICATOR (watershed level) | Units | INFLUENCE | DataSource |
|---|---|---|---|---|
| **Potential for Ground Water Recharge** | Average annual Rainfall (as an indicator of Water availability) | mm | 60% | CHIRPS Satellite Data |
| | Area under Rangelands (sq.km) | Sq. km | 20% | FAO,SUPARCO |
| | Area under Wetlands (sq.km) | Sq. km | 20% | FAO,SUPARCO |
| | **Total** | | **100%** | |
| **Potential for Surface Water harvesting** | Average annual rainfall for 20 years (mm) | mm | 70% | CHIRPS Satellite Data |
| | Run-off potential based on soil texture | mm | 20% | FEWSNET |
| | Population density | Count per sq.km | 10% | LANDSCAN 2020 |
| | **Total** | | **100%** | |
| **Potential For Livestock Based Interventions** | Livestock Density | Count District wise | 30% | FAO |
| | Area under rangelands (sq.km) | Sq.km. | 60% | FAO, SUPARCO |
| | Condition of rangelands | qualitative | 10% | FEWSNET, MODIS |
| | **Total** | | **100%** | |

All these criteria are of spatial nature and quantify in different units and ranking between them may vary. So, it is important to make them consistent both in quantitative way and in spatial domain. In spatial domain we will divide all the factor in a regular grid of 1km spatial resolution. On grided data we can perform simple arithmetic operation, logical condition, and boolean operations for overlaying. Once overlay will be done the result will cumulate at the watershed boundaries.

The factors defined above are the physical quantities, which are both quantitative and qualitative in nature. To make them consistent, they are discuss one by one along with their sources.

## 4.1 PRECIPITATION

Precipitation is the major source of water within the water catchment. We can use CHIRPS dataset that can be downloaded from USGS website. The dataset provides the precipitation calculated in millimeter (mm) on hourly, daily, monthly and yearly bases with a spatial resolution of 0.05 degree which is almost 5.5 Km. It is recommended to take at least 20 years of data and calculate the minimum rainfall in the basin. Calculate the probabilistic map by determining the return period of minimum rainfall at each pixel. Finally normalize the probability between 0 to 1 using min max stretch shown in equation 2.

$$Recurrence\ Interval = \frac{n+1}{m} ----(1)$$

Where
$n = no\ of\ years\ on\ records$
$m = rank\ of\ observed\ occurrences\ when\ arranged\ in\ decending\ order$

$$R_n = \frac{(P_{ij} - P_{min})}{(P_{max} - P_{min})} \quad ----- (2)$$

Where
$R_n = Normalized\ Raster$
$P_{ij} = Pixel\ value\ at\ i^{th} and\ \ j^{th}$
$P_{max} = Maximum\ Pixel\ value$
$P_{min} = Minimum\ Pixel\ value$
The normalized raster will of 5.5 Km resolution. To make consistent in spatial domain we will downscale it to 1Km resolution.

## 4.2 LAND USE/LAND COVER (LULC)

Land use and Land cover indicates socio-economic purpose of the land and visible surface of the land respectively. The visible surface of the land is classified as vegetation, water, barren, and settlements. These classes can be determined on a satellite imagery like Landsat (15 m resolution) or Sentinel (10 m resolution) using indices like NDVI (Vegetation Indices), NDWI (Water Indices), and NDBI (Built up Indices). Each class will be separated as individual classified raster by using masks based on threshold value.
A distance raster will be created for each classified raster using equation 3. Since watershed selected should be close to vegetation area, wetlands, and built-up area it is recommended to normalize the raster using equation 4.

$$R_d = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad ------- (3)$$

Where
$R_n = Normalized\ Raster$
$x_i\ ,\ \ y_i\ = x\ and\ y\ value\ of\ i\ Pixel$
$x_j\ ,\ \ y_j\ = x\ and\ y\ value\ of\ nearst\ LULC\ Pixel$

$$R_n = 1 - \frac{(d_{ij} - d_{\min})}{(d_{max} - d_{\min})} ------(4)$$

where
$R_n = Normalized\ Raster$

$d_{ij} = Distance\ between\ i^{th}\ and\ j^{th}\ pixel\ and\ the\ nearest\ classified\ pixel$
$d_{max} = Maximum\ distance\ value$

Finally, the normalized Raster will downscale to 1 Km resolution to make it consistent in spatial domain.

## 4.3 POPULATION DENSITY

It is important to have watershed close to densely population cluster. Lands can data is excellent for this purpose. It provides number of people per sq. km. We need to normalize the data using logarithmic scaling as shown in equation 5. The logarithmic scaling is recommended as it grow very slow for large value and population tends to extremely high in urban areas especially metropolitan area like Quetta.

$$R_n = \ c * \log(1 + \ P_{ij}) - - - - -(5)$$
$$c = \frac{1}{1 + P_{max}} - - - (6)$$

Where
$R_n = Normalized\ Raster$
$P_{ij} = Population\ at\ i^{th}\ and\ j^{th}\ pixel$
$c = scaling\ constant\ defined\ as$
$P_{max} = Maximum\ Population$

## 4.4 LIVESTOCK DENSITY

Livestock density is at the district level which vary in size. The district polygon will convert into a grid of 1 Km resolution and each pixel will have the same value as of district level count. The grided data will then be normalized using min max scaling as defined in equation 2.

## 4.5 IRRIGATION SYSTEM

Irrigation system ranges from ground water to surface water. The ground water are used through pumping and kareez system. The surface water is used through spate irrigation, canal system, and commanded area of the small Dams.  The most of the irrigation system are linear infrastructure, to create distance raster it is required to calculate the perpendicular distance between the pixel of grid and the irrigation network using equation 7. The distance raster is finally normalized using equation 4

$$d = \frac{ax+by+c}{\sqrt{a^2+b^2}} ------ (7)$$

Where
$d = perpendicular\ distance\ between\ pixel\ and\ a\ line$

$a, b, c = staright\ line\ constants$

### 4.6 SOIL CHARACTERISTICS

Soil data can be downloaded from the ISRIC website which contain the world soil data. They provide data in WMS format and different parameter like Clay, Sand, Silt, Nitrogen, PH, Bulk Density, Soil Organic Carbon Density, and Soil Organic Carbon Content can be downloaded. Using these parameters, we can calculate soil field capacity, using equation 8, which is the amount of soil moisture held in soil after excess water has drained away.

$$\theta_{fc} = \theta_{res} + \frac{(\theta_{sat} - \theta_{res})}{(1 + (0.02 * 200)^{ng})^{(1-1/ng)}} - - - - (8)$$

Where

$$\theta_{sat} = 0.85 * \left(1 - \frac{bulk_{density}}{2.65}\right) + 0.13 * \frac{Clay}{100} - - - - (8)$$

$$\theta_{res} = \begin{matrix} 0.01 & if\ \theta_{sat} < 0.351 \\ 0.27 * \log \theta_{sat} + 0.335 & else \end{matrix} \text{ ----- (9)}$$

$$ng = 166.63\, \theta_{sat}^4 - 387.72\, \theta_{sat}^3 + 340.55\, \theta_{sat}^2 - 133.07\theta_{sat} + 20.739 \text{ ---- (10)}$$

The soil field capacity raster is normalized using min max stretch shown in equation 2.

## 5 PREPARATION OF FINAL SCORE RASTER

Once all indicator processed and prepared as shown in Table 1 and explained in above section. We will combine these output rasters using simple average, considering each raster has same weightage, to prepare **final score raster** at a resolution of 1 Km. Watershed boundaries, prepared as mentioned under the heading of watershed delineation, will use to accumulate the scores to give a total score to each watershed. The highest score watershed will be selected for survey

TABLE 1: INDICATOR PROCESSING

| Indicator | Processing | Output | Output Range |
|---|---|---|---|
| Precipitation | Probablistic map based on Return Period | 1km resolution raster | 0 - 1 |
| LULC (Vegitation Area) | Inverse distance raster based on NDVI Vegitation Mask | 1km resolution raster | 0 - 1 |
| LULC (Water Bodies) | Inverse distance raster based on NDWI Water Mask | 1km resolution raster | 0 - 1 |

| | | | |
|---|---|---|---|
| LULC(Builtup Area) | Inverse distance raster based on NDBI Settlement Mask | 1km resolution raster | 0 - 1 |
| Population Density | Landscan data normalized using Min Max Stretch | 1km resolution raster | 0 - 1 |
| Irrigation Network | Inverse distance raster from irrigation network | 1km resolution raster | 0 - 1 |
| Livestock | FAO Livestock downscale data normalized using Min Max Stretch | 1km resolution raster | 0 - 1 |
| Soil Field Capacity | $\theta fc$ Calculation using Soil Grid data of ISRIC and Normalized using Min Max Stretch | 1km resolution raster | 0 - 1 |