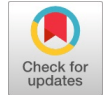


Water Balance Evaluation of Chandigarh Region, India.



Nitish Kumar Sharma, Varinder S Kanwar, Harpreet Singh Kandra

Abstract: The water balance is an accounting of the inputs and outputs of water. The water balance of a place, whether it is an agricultural field, watershed, or continent, can be determined by calculating the input, output, and storage changes of water at the Earth's surface. The assessment also takes into account the existing supply of stocks and future appropriation of these stocks. Water inputs are brought by precipitation. Outputs are from the combination of evaporation and the transpiration of plants, called evapotranspiration. Both quantities are estimated in terms of the amount of water per surface unit, but they are generally translated into water heights, the most currently used unit being the millimeter. Usually, the planning and implementation of water use is undertaken in silos with little or no interaction between and across sectors. This leads to frequent water scarcity and water pollution. About 30% of people in India live in cities that are expected to double in population by 2050. With a growing economy and changing lifestyles the pressure on already strained water resources is increasing. The government has shown an interest in Integrated Urban Water Management (IUWM) as a new framework and approach for thenation.

Index Terms: Water Balance, Sustainable urban water management; Sustainability criteria; Criteria prioritization.

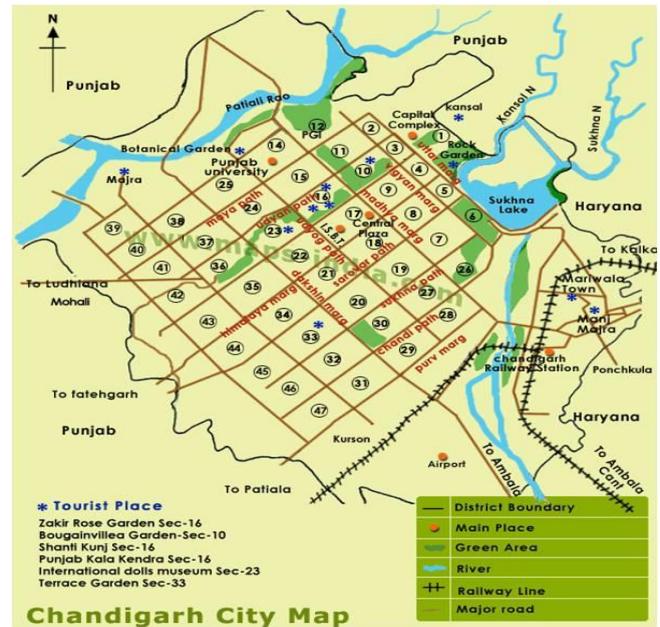


Figure 1.1: Study Area

(Source: Municipal Corporation Chandigarh)

I. INTRODUCTION

A water balance equation can be used to describe the flow of water in and out of a system. A system can be one of several hydrological domains, such as a column of soil or a drainage basin.

A general water balance equation is:

$$P_i = R_s + E_v + \frac{dS}{dt} \text{ where,}$$

P_i is precipitation

E_v is evapotranspiration

R_s is stream flow

dS/dt is the change in storage (in soil or the bedrock / ground water)

This equation uses the principles of conservation of mass in a closed system, whereby any water entering a system (via precipitation), must be transferred into either evaporation, surface runoff (eventually reaching the channel and leaving in the form of river discharge), or stored in the ground. This equation requires the system to be closed, and where it isn't (for example when surface runoff contributes to a different basin), this must be taken into account.

1.1 WHAT IS WATER BALANCE?

A water balance can be used to help manage water supply and predict where there may be water shortages. It is also used in irrigation, runoff assessment (e.g. through the Rain Off model), flood control and pollution control. Further it is used in the design of subsurface drainage systems which may be horizontal (i.e. using pipes, tile drains or ditches) or vertical (drainage by wells). To estimate the drainage requirement, the use of a hydrogeological water balance and a groundwater model may be instrumental.

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Each water system is unique in that the source and amount of water flowing through the system is dependent upon external factors such as rate of precipitation, location of streams and other surface water bodies, and rate of evapotranspiration. The one common factor for all water systems, however, is that the total amount of water entering, leaving, and being stored in the system is in balance. An accounting of all the inflows, outflows, and changes in storage is called a water balance. The study of water balances is complicated by the fact that the two commanding variables are not independent of each other. The quantity of evaporated water obviously depends on the total available quantity of water: it stops when the water volume brought by precipitation is exhausted. This has led to the introduction of the notion of potential evapotranspiration: the quantity of water that can go into the atmosphere according to its state alone, assuming that the quantity of available water is not a limiting factor. (The amount of water added to a vase of flowers in order to keep its level constant is a measure of the potential evapotranspiration, depending on the state of the atmosphere in the place where the vase is located.) It is usual, in the study of water balances, to compare precipitation, P and potential evapotranspiration, ETP , which makes it possible to distinguish different situations according to thresholds that are of special significance for a given place or period of time:

- If $P < ETP$, the real evaporation will be equal to P ; there will be an appropriation of reserves and an absence of runoff; the period will be said to be a deficit period.
- If $P > ETP$, the real evaporation will be equal to the ETP ; there will be runoff and a building up of reserves; the period will be called surplus period.

1.2 DEFINITION OF KEY VARIABLES IN WATER BALANCE STUDY

Precipitation

Precipitation is any form of water that falls to the Earth's surface. Different forms of precipitation include drizzle, rain, hail, snow, sleet. Precipitation is a major component of the water cycle and is responsible for depositing the fresh water on the planet. Approximately 505,000 cubic kilometres (121,000 cubic miles) of water falls as precipitation each year; 398,000 cubic kilometres (95,000 cubic miles) of it over the oceans (Chowdhury, 2005). Given the Earth's surface area, that means the globally averaged annual precipitation is 990 millimetres (39 inch).

EVAPOTRANSPIRATION

Evapotranspiration (ET) means transport of water into the atmosphere from surfaces, including soil (soil evaporation), and from vegetation (transpiration). The latter two are often the most important contributors to evapotranspiration. Other contributors to evapotranspiration may include evaporation from wet canopy surface (wet-canopy evaporation), and evaporation from vegetation-covered water surface in wetlands.

The process of evapotranspiration is one of the main consumers of solar energy at the Earth's surface. Energy used for evapotranspiration is generally referred to as latent heat flux; however, the term latent heat flux is broad, and includes other related processes unrelated to transpiration including condensation (e.g., fog, dew), and snow and ice sublimation. Apart from precipitation, evapotranspiration is one of the

most significant components of the water cycle. Assuming that moisture is available, evapotranspiration is dependent primarily on the availability of solar energy to vaporize water. Evapotranspiration therefore varies with latitude, season of year, time of day, and cloud cover. Most of the evapotranspiration of water on the Earth's surface occurs in the subtropical oceans. Evaporation can be classified as Actual evapotranspiration (AE or AET), Potential evapotranspiration (PE or PET)

Actual evapotranspiration (AE or AET) is the quantity of water that is actually removed from a surface due to the processes of evaporation and transpiration. While Potential evapotranspiration or PE is a measure of the ability of the atmosphere to remove water from the surface through the processes of evaporation and transpiration assuming no control on water supply. Since PET assumes that water availability is unlimited, vegetation would never reach the wilting point (the point in which there is not enough water left in the soil for a plant to transpire). Therefore, the only limit to the transpiration rate of the plant is due to the physiology of the plant and not due to any atmospheric or soil moisture restrictions. Therefore, PET is considered the maximum ET rate possible with a given set of meteorological and physical parameters. On this basis, any irrigation that supplies more water than PET can accommodate could be viewed as wasted water.

1.3 IMPORTANCE OF WATER BALANCE

The concept of water balance provides a framework for studying the hydrological characteristics and behavior of a catchment. The estimation of water balance is necessary in water resources development not only for economic appraisal of the project but also for checking the reliability and general pattern of availability of water on a monthly or yearly basis. The planning, development and operation of water resources project is dependent upon the availability of water in the required quantity. Water balance study is an essential part before deciding for an irrigation project. A water balance provides a means of testing, confirming or refining our hydrological understanding of the system. The modeling approach may be a useful tool to refine our understanding of the system.

1.4 SUSTAINABLE WATER MANAGEMENT

Sustainable Water Management is simply to manage our water resources while taking into account the needs of present and future users. However, it involves much more than its name implies.

It involves a whole new way of looking at how we use our precious water resources. The International Hydrological Programme, a UNESCO initiative, noted:

"It is recognised that water problems cannot be solved by quick technical solutions, solutions to water problems require the consideration of cultural, educational, communication and scientific aspects. Given the increasing political recognition of the importance of water, it is in the area of sustainable freshwater management that a major contribution to avoid/solve water-related problems, including future conflicts, can be found."

Therefore, it attempts to deal with water in a holistic fashion, taking into account the various sectors affecting water use, including political, economic, social, technological and environmental considerations. A key issue of sustainable water management is balancing the available resources with the increasing demands of water use. To that end, the following resources management objectives are crucial:

- Balancing groundwater recharge against abstraction is the main emphasis of groundwater management.
- Sustainable management of water resources cannot be achieved only by addressing surface water management but must include groundwater. A new approach guided by IWRM principles and goals is needed for water resource governance and management.

REFERENCES AND FURTHER READING

1. Cap-Net, 2005, IWRM Plans Manual. <http://www.cap-net.org/node/1515>.
2. Dr. Chowdhury's Guide to Planet Earth, 2005, "WestEd.http://www.planetguide.net/book/chapter_2/water_cycle.html. Retrieved 24-10-2006.
3. GWP, 2004, Catalyzing Change: A handbook for developing integrated water resources management (IWRM) and water efficiency strategies, ISBN: 91-974559-9-7, www.gwpforum.org/gwp/library/Catalyzing_change-final.pdf.
4. Kapp, H.V., 1985, Evaporation and Transpiration, In Handbook of Applied Meteorology, ed. D. Houghton, pp. 537-554, New York: John Wiley and Sons, Inc.
5. Sustainable Water Management, <http://www.dainet.org/water/intro.htm>.
6. Watson, I. and Burnett, A.D., 1995, Hydrology: An environmental approach, Boca Raton, FL: CRC Press.

II. EXPERIMENTAL

This study includes all the tests related to water balance and water quality. All the tests were performed in the environment lab and data was collected from Environment Information Centre and Meteorological Department, Sector 19 and 39, Chandigarh.

III. LITERATURE REVIEW

3.1 Estimating groundwater balance components - state of the art

The problems related to groundwater management are clear, but the solutions are not. An increasing emphasis is laid on how to manage ground and surface water in a sustainable manner (Downing 1998; Sophocleous 1998). A major impediment to finding solutions is the lack of quantitative understanding of the interaction between surface and groundwater. It is generally accepted that the interaction of climate, geology, morphology, soil condition and vegetation determine to varying degrees the recharge process to varying degrees (Simmers 1997; De Vries and Simmers 2002). Groundwater recharge in semiarid areas is more susceptible to near surface conditions as compared to humid areas; the potential evaporation is higher than the rainfall making recharge dependent on rainfall. However, more subtle considerations may affect the recharge process. Defining direct groundwater recharge as the downward flow of water

to the saturated zone creates conceptual problems regarding the recharge processes (De Vries and Simmers 2002).

Just as the net rainfall reaching the ground is reduced by interception not all percolating water may not necessarily reach the water table. Percolation may be hampered by low vertical conductivity horizons resulting in lateral flow to nearby depressions (De Groen 2002). Direct evaporation and transpiration from the saturated zone also results in reduction of total recharge to aquifer (De Vries and Simmers 2002). Even though these interactions control the behavior of groundwater flow systems, recharge to the aquifer and subsequent man-induced groundwater extractions are uncertain, which are reflected in the quantitative description of interaction between surface and groundwater systems change. Solving this question requires a complete understanding of the hydrological processes at the land surface in relation to the aquifers. Significant research efforts have addressed the estimation of various components of groundwater balance. In these investigations, several approaches, such as physical, chemical and numerical modeling techniques, have been developed by (Simmers 1988; Cook et al. 1990; Gieske 1992). These can be grouped into five categories: empirical methods, direct measurements, tracer techniques, Darcian approaches, and water balance methods (Lerner et al. 1990). The choice and application of methods depend on many factors. It is often reported that in arid and semiarid regions, groundwater recharge is heterogeneous in both time and space (Hendrickx and Walker 1997). Simmers (1988) reported that "no single comprehensive estimation technique can yet be identified from the spectrum of methods available; all are reported to give questionable results". Therefore, for reliable quantification and prediction of spatially distributed recharge, it is recommended to use more than one method. This is a tedious task for most of the arid and semiarid regions because of wide spatial and temporal variations and scarce hydro-geological information. Groundwater use estimates in large irrigated schemes are often based on the number of tube wells, their discharge capacity and their operational hours (Maupin 1999). The operational hours are calculated from electricity/fuel usage or through surveys in that irrigation scheme. Such estimates only provide a range of groundwater extraction values and do not account for groundwater recycling. Recent advances in remote sensing techniques make it possible to estimate various hydrological parameters with increasing accuracy, especially in the fields of irrigated area and actual evapotranspiration mapping (Bos et al. 2001). Remotely sensed information on these parameters enhances our understanding of the hydrologic cycle (Lerner et al. 1990; Cook et al. 1992). An innovative avenue is to integrate Remote Sensing (RS), Geographical Information System (GIS), geo-statistics and selective ground data. This geo-information can help in describing the spatial variation in hydrological processes, notably the water fluxes at the land atmosphere interface, groundwater use and recharge in a data scarce environment.

Recharge estimation is a major and pivotal research in the present day world due to tremendous pressure on groundwater resources. Groundwater recharge from water storage structures under semiarid conditions of western India has been estimated by employing water table fluctuation (WTF) and chloride mass balance (CMB) methods. Groundwater recharge was estimated as 7.3% and 9.7% of the annual rainfall by WTF method for the years 2003 and 2004, respectively while the two years average recharge was estimated as 7.5% using CMB method (Sharda et al. 2006). Water table fluctuation methods are used in computing recharge as the method is simple and assumptions are very less. The WTF method is best applied to systems with shallow water tables that display sharp rises and declines. Marechal et al. (2006) and Zaidi et al. (2007) have used double WTF method to compute recharge in Maheshwaram watershed of A.P. The study demonstrates that DWTF is an efficient recharge estimation method but the accuracy of this method depends on the representativeness of the piezometric data of the area from which the water table fluctuations are calculated. Therefore, the measurement density is of utmost important. A very high measurement density will increase the time and cost of field measurement and on the other hand, a very low measurement density can result in losing vital information. Dewandel et al. (2007) have reported a decline of 5-6 meters in water level of Maheshwaram watershed of Rangareddy district of A.P from 2000 to 2005.

Several studies have shown that reasonable regional groundwater recharge estimates can be obtained using readily available field data without considering small-scale local variations. Methods used include isotope dating chloride mass balance calculation and mixing cell modeling Darcian flow modeling and direct measurement of stream and spring discharge (Adar and Numen 1988; Gieske and De Vries 1990; Van der Lee and Gehrels 1990). Quantifying the current rate of groundwater recharge is a basic prerequisite for efficient groundwater resource management and is practically vital in arid and semiarid regions where such resources are often the key to economic development (Simmers 1997). Simmers et al. (1997) indicate that the procedures to quantify recharge from various sources include direct measurements, water balance methods, tracer techniques and empirical methods. A number of methods were used to estimate groundwater recharge in semiarid climatic conditions in India (Sharda et al. 2006). As part of the study, water table fluctuation and chloride mass balance methods were applied. The water table fluctuation is based on the principle that the rise in groundwater level in any aquifer is proportional to the water reaching the water table.

De Vries and Simmers (2002) identifies some challenges in the estimation of groundwater recharge and the need to fully understand the temporal and spatial variability of recharge, development of various methods to estimate recharge from point measurements and fully deciphering the impact of land use particularly in urban developments on groundwater recharge. The water resources management challenge is however, to find cost-effective, simple and rapid assessment methods for estimating recharge.

3.2 Direct methods

Direct measurements with lysimeters containing undisturbed soil profiles are potentially the most accurate method for estimating recharge and evapotranspiration. The main problem with this method is that it is difficult, time consuming and expensive to set-up (Gee and Hillel 1988). The results represent point scale information and their application is limited to experimental studies. They are more suitable for humid climates than for arid to semiarid climates. Because the recharge process is quick in humid regions, data collected over a short time period are sufficient to get complete insight into the recharge process. Bredenkamp et al. (1995) noted that lysimeter results indicate an apparent annual threshold value of rainfall below which no recharge takes place. A lysimeter is a device, consisting of an in situ weighable column or volume of soil for which the inflow and outflow water can be measured and changes in storage can be monitored by weighing. These techniques used to determine evaporation in a natural environment by measuring the other water balance components, but as is mentioned above measuring recharge using this technique at reasonable spatial scale is difficult.

3.3 Empirical methods

These methods are often used in a data scarce environment. Empirical methods seek to correlate recharge with other measurable hydrological data such as rainfall and surface flow through the use of mathematical formulae and equations (Sinha and Sharma 1988; Lerner et al. 1990; Sami and Hughes 1996). The advantage of such approaches is that they can be transposed in time and space and render themselves practically useful for preliminary recharge estimates. Their main disadvantage is that they are site specific and derived from other methods of recharge estimation. As such they can only be as accurate as the methods from which they are derived. Secondly, since they are not physically based they can be rendered obsolete by changes in catchment physiology, if not reviewed periodically. Despite this setback, many researchers consider them of valuable importance in estimating recharge for water resources management purposes particularly in areas of data scarcity and limited technical and financial resources. An improvement to the empirical methods can be termed the 'hybrid method'. In this approach combining physically based techniques with empirical methods reduces somewhat the shortcomings of the latter. Such an approach combines the influence of climate, geology, terrain geometry and land cover on recharge into a single estimate.

3.4 Water balance methods

Water balance methods are applicable for both point and basin scale estimates. They have three categories: soil water balance, river channel water balance and groundwater (saturated zone) balance. The major advantage of water balance methods are that they use readily available data, can be applied rapidly and account for all water entering and leaving the system.

But, the major disadvantage of these methods is that recharge is the residual term, so their accuracy depends upon the accuracy of all the other water balance terms. If these groundwater balance methods include some spatial averaging, the degree of averaging is usually unclear and depends upon the density of observation points. Their application is limited to data scarce environments in semiarid regions. The basis of the soil moisture balance method of estimating recharge is that the soil becomes free draining when the moisture content of the soil reaches a limiting value called the field capacity. To determine when the soil reaches this critical condition, it is necessary to simulate soil moisture conditions throughout the year. This involves the representation of the relevant properties of the soil and the capacity of crops to collect moisture from the soil and to transpire water to the atmosphere. If no crops are growing or if there is only partial crop cover, bare soil evaporation must be considered. Bare soil evaporation is important both in semiarid locations to represent soil moisture conditions at the end of the dry season and in temperate climates where recharge occurs in winter when evaporation is usually the major loss from the soil. Transpiration and evaporation often occur at less than their potential rate due to crop stress arising from limited soil moisture availability. The input to the soil moisture balance is infiltration which equals the daily precipitation minus interception or runoff. The soil moisture balance is often written as:

$$R = P + Q + ET + W \dots \dots \dots 3.1$$

Where; R is recharge, P is precipitation, Q is net runoff, ET is actual evapotranspiration and W is the change in soil moisture storage.

3.5 Hydrological models

Different types of models are available for determining recharge: one-dimensional semi-distributed numerical models such as SWAP, one-dimensional lumped parametric models such as EARTH and three-dimensional fully distributed numerical groundwater flow models such as MODFLOW. The advantage of the hydrological models is that the impact of transferring water between competing sectors can be simulated and the effects of man-induced scenarios on regional hydrology can be studied. The disadvantage though is that considerable expertise in model use and extensive field data are required to make proper model simulations at regional scale feasible. The unsaturated zone physically based numerical models such as SWAP solve the unsaturated zone water flow equation i.e. the Richards equation for porous media. In contrast to the lumped parametric water balance models, numerical models allow detailed evaluation of the effects on groundwater recharge of vadose zone hydraulic properties and their spatial variability. These methods are based on soil profile partitioning with a number of homogeneous layers with their own characteristic hydraulic properties. They simulate the transformation of precipitation into flow taking into account all the intermediate processes such as evapotranspiration, interception, infiltration and runoff. They are therefore able to estimate recharge at many points and at many times. For simulating recharge, boundary and initial conditions must be

imposed on the models together with hydraulic soil properties and vegetation properties.

Parametric models such as EARTH use a numerical or analytical relationship between precipitation and recharge. These models have been developed to deal with conceptual recharge situations that cannot be encompassed by existing numerical models. Examples are recharge through hard rock formation. Some researchers have used both the SWAP and EARTH models to predict groundwater fluctuations in the Veluwe area which is characterized by porous media, and both models could describe the deep groundwater level fluctuation quite well. Thus the parametric models such as Earth can be used both in porous and hard rock formations.

Another common method is to use a fully distributed three-dimensional numerical groundwater flow model (such as MODFLOW) to estimate recharge by adjusting the recharge input value in the model until groundwater levels calculated by the model match the aquifers measured water levels. One problem with this approach is that any change in aquifer parameters such as hydraulic conductivity and aquifer storage also affects the calculated water levels. Often the uncertainty associated with transmissivity is larger than the uncertainty associated with recharge, thus the accuracy of the estimated recharge may be low.

3.6 Tracer methods

Tracer techniques are among the most widely used methods for recharge estimation in arid and semiarid regions. They too, only provide point or field scale information. There are three kinds of tracers. However, the most commonly used in this field are the environmental tracers. These are dissolved substances introduced into the large scale water cycle either by nature or by man over long periods of time. They are able to trace water movement over long periods in contrast to artificially applied tracers which show water movement over small spatial and temporal scales. The most important tracer is chloride. Conservative tracers like chloride are the norm in most investigations. Though convenient and sometimes the only available method for arid areas, tracer methods suffer the handicap of mass distortions from secondary inputs and mixing and/or dual flow mechanisms (Beekman et al. 1996). Lerner et al. (1990) and Simmers (1997) advocated that tracer methods are more successful recharge estimation methods than the indirect physical methods because they are simple to use, relatively cheap and universally applicable. However, Cook and Walker (1995) caution that vapour transport particularly for tritium profiling, can affect the results for recharge estimates below 20 mm year⁻¹. Selaolo (1998) further warns that not only is it difficult to determine the atmospheric deposition of chloride but the deposition has considerable temporal and areal variability. Despite these shortcomings tracer methods remain the most widely used for all types of groundwater recharge estimates in semiarid areas. To reduce the margin of error in estimation the trend has been to use methods in combination either as multiple tracer methods or as tracer and some physical method.

In Indian scenario a linear relation between rainfall and natural recharge exists for all the four major hydrogeological units granites, basalt, sediments (mainly sandstone) and alluvium (Rangarajan and Athavale 2000).

Tritium based recharge estimation has been applied to estimate recharge in Kongal river basin of Nalgonda district, A.P. The computed average recharge was estimated to be 5% of annual rainfall (Chand et al.2005).

3.7 Darcian approach

The Darcian approach analyzes the water fluxes in the unsaturated zone. The information from this method is valid only for field scale studies (Cook et al. 1990), although it is often used for climate studies (Sellers et al. 1996). The principal advantage of this method is an attempt to identify the actual physical processes of water flow in the unsaturated zone. The application of Darcian methods to the unsaturated zone has been hampered by the reliance on soil parameters like the unsaturated hydraulic conductivity which are difficult to determine. Van Genuchten and Leij (1992) developed simplified methods based on soil data to counter this issue. Efforts have also been made to estimate groundwater recharge as a function of soil temperature changes in the unsaturated zone (Taniguchi and Sharma1993).

IV. MATERIAL AND METHODOLOGY

4.1 VARIOUS METHODS OF CARRYING OUT WATER BALANCE STUDY

Many regions are facing formidable freshwater management challenges. Allocation of limited water resources, concerns regarding environmental quality, planning under climate variability and uncertainty, and the need to develop and implement sustainable water use strategies are increasingly pressing issues for water resource planners. Conventional supply-oriented simulation models are not always adequate for exploring the full range of management options. In order to calculate water storage a number of methods can be used from simple to complex.

Method 1: The simplest one is

$$P = ET + dS/dt \dots \dots \dots \text{Eq. 4.1}$$

This method is particularly useful for a catchment area where vegetation types are known and surface runoff and infiltration are negligible as compared to evapotranspiration. Since infiltration is too small and hence storage of groundwater would be too small to consider here. This method can be widely applied in a large catchment area and water balance can be computed based on future climate scenario with changes in precipitation and evapotranspiration. The snow cover and melting of ice affect has also been neglected as most of the developing countries are located in tropical or arid regions. Precipitation influences the plant species, quality and quantity of water consumption, root depth and shading conditions (Comstock and Ehleringer, 1992). It has been also observed that old trees do not use surface water but consume water from deep layers and therefore have less significance on water balance (Dowson and Ehleringer, 1991). Complexity of interactions between elements of atmosphere-plant-soil system and temporal

variability of vegetation cover, amount of available water and dynamic atmosphere conditions are the agents for complexity of ET computations that take place in the form of water vapour fluxes, a common parameter in water and energy balance equations; that has been identified as a key factors in hydrological modeling. For this reason several methods have been developed to calculate potential evapotranspiration (ETP) (Buttafuoco et al., 2010). ETP is an essential parameter for computation of effective recharge and evaporation from ground water. There are some known methods as Pennman-Monteith, Thorwaite and Hragreaves, Hamon and FAO56-PM to compute ETP. There is not much differences between them and FAO56-PM is more suitable for computation of ETP because of its simplicity (Alkaeed et al.,2006).

Method 2: This method is more accurate than the previous method as it calculates runoff and infiltration with precipitation and evapotranspiration as shown in the eq. below

$$P = ET + R + I + dS/dt \dots \dots \dots \text{Eq. 4.2}$$

Since runoff and infiltration depends on the soil type and hence geological characteristics of the catchment area is required to be known to calculate runoff. The catchment area can be sub-divided into a number of small segments with its geo-characteristics known. The use of GIS data could be very helpful to identify the soil profile or spatial distribution of the catchment area. The storage Δs for each segment can be computed and summed up to estimate the total storage.

The direct run-off is estimated using the SCS-CN method (Soil Conservation Service, 1972). The SCS method has been successfully used as it gives consistently usable results for run-off estimation (Rao et al., 1996; Yu, 1998; Sharma et al., 2001; Chandramohan and Durbude, 2001; Sharma and Kumar, 2002). The SCS method uses the following Equations

$$R = (P - 0.2S)2 / (P + 0.8S) \text{ if } P > 0.2S$$

$$\text{and } R = 0 \text{ if } P < 0.2S$$

where R is the accumulated run-off volume or rainfall excess, P is the precipitation, and S is the maximum soil water retention parameter, computed from

$$S = (25000/CN) - 254 \quad (Q, P \text{ and } S \text{ in mm}),$$

where CN are the curve numbers (Soil Conservation Service, 1972).

Method 3: This method is the most accurate one as net groundwater water flow out of the catchment, G and withdrawal or extraction of water, W by human for water supply or agricultural consumption is taken into consideration.

$$P = ET + R + I + G + W + dS/dt \dots \dots \dots \text{Eq. 4.3}$$

The groundwater flow or subsurface lateral flow can be computed using hydrograph. While runoff and infiltration depends on the soil type.

The catchment area can be sub-divided into a number of small segments using GIS data and computation can be carried out. However, the total withdrawal of water needs to be calculated and it has to be deducted from computed total storage ΔS to obtain the final storage of a catchment area.

Method 4: This method is the easier and accurate one as recharge by rainfall, recharge by canals, recharge by field irrigation, total recharge, average annual drought is taken into consideration.

$$\text{Water Balance (W)} = R - D \times 10^6 \text{M}^3 \dots \dots \dots \text{Eq. 4.4}$$

REFERENCES AND FURTHER READING

1. Akivaga, E. M., Fred A. O. Otieno, F. A. O., Kipkorir, E. C., Kibiiy, J. and Shitote, S., 2010, Impact of introducing reserve flows on abstractive uses in water stressed Catchment in Kenya: Application of WEAP21 model, *International Journal of the Physical Sciences* Vol. 5, No.16, pp. 2441-2449, Available online at <http://www.academicjournals.org/IJPS>.
2. Alkaeed, O., Flores, C., Jinno, K. and Tsutsumi, A., 2006, Comparison of several reference evapotranspiration methods for itoshima peninsula area, Fukuoka, Japan, *Memoirs of the Faculty of Engineering, Kyushu University*, Vol. 66. No.1.
3. Buttafuoco, G. T., Caloiero and Coscarelli, R., 2010, Spatial uncertainty assessment in modeling reference evaporation at regional scale, *Hydrol. Earth. Syst. Sci.*, Vol. 14, pp. 2319-2327.
4. Chandramohan, T. and Durbude, D. G., 2001, Estimation of runoff using small watershed models, *Journal of Hydrology*, Vol. 24, No. 2, pp.45-53.
5. Comstock, J. P. and Ehleringer, J. R., 1992, Plant adaptation in great basin and Colorado Plateau, *Great Basin Nat.*, Vol. 52, pp. 195-215.
6. Condom, T., Escobar, M., Purkey, D., Pouget, J. C., Suarez, W., Ramos, C., Apaestegui, J., Zapata M., Gomez, J. and Vergara, W., 2011, Modelling the hydrologic role of glaciers within a Water Evaluation and Planning System (WEAP): a case study in the Rio Santa watershed (Peru). *Hydrology Earth System Science Discussion*. Vol. 8, pp. 869-916, 2011, www.hydrol-earth-syst-sci-discuss.net/8/869/2011/.
7. Dowson, T. E. and Ehleringer, J. R., 1991, Streamside trees that do not use stream water, *Nature*, Vol. 350, pp. 335-337.
8. Hall, J. and Murphy, C., 2010, Vulnerability Analysis of Future Public Water Supply Under Changing Climate Conditions: A Study of the Moy Catchment, Western Ireland, *Water Resource Management*, Vol. 24, pp. 3527-3545.
9. Ospina-Norena, J. E., Gay-Garcia, C. and Conde, A. C., 2011, Water availability as a limiting factor and optimization of hydropower generation as an adaptation strategy to climate change in the Sinú-Caribe river basin, *Atmósfera*, Vol. 24, No. 2, pp. 203-220.
10. Rao, K. V., Bhattacharya, A. K. and Mishra, K., 1996, Runoff estimation by curve number method – case studies, *Journal of Soil Water Conservation*, Vol. 30, No. 2, pp.141-145.
11. Sharma, D. and Kumar, V., 2002, Application of SCS model with GIS data base for estimation of runoff in an arid watershed, *Journal of Soil and Water Conservation*, Vol. 30, No. 2, pp.141-145.
12. Sharma, T., Satya, K. P. V., Singh, T. P., Trivedi, A. V. and Navalgund, R. R., 2001, Hydrologic response of a watershed to landuse changes: a remote sensing and GIS approach, *Int. J. of Remote Sensing*, Vol. 22, No. 11, pp. 2095-2108.
13. Soil Conservation Service, 1972, *Soil Conservation Service, US Dept. of Agriculture National engineering handbook*, Section 4, hydrology, Chapters 7-10. US Govt. Print. Off. Washington, DC.
14. Yates, D., Sieber, J., Purkey, D. and Huber-Lee, A., 2005, WEAP21 - A demand, priority and Preference driven water planning model, Part 1: model characteristics, *Water International*, Vol. 30, pp. 487-500.

V. CHANDIGARH DATA FOR WATER BALANCE STUDY

5.1 Treated Water & STP's Data

Chandigarh is completely secured with sewerage office and furnished with the 100% sewerage treatment facility. Out of 87 MGD water being provided to the occupants of the city, 57

MGD sewage effluent is being created every day. Out of which, normal 53.85 MGD waste water is treated consistently. Perceiving the significance of water, Chandigarh had, prior in 1991, started tertiary treatment of wastewater at Diggian STP (10 MGD) and later provided it for the non-consumable uses, for example, water system of greenery enclosures, green belts and yards, washing autos and so forth., to various divisions. Directly, the introduced limit with respect to tertiary treatment is 20 MGD at Diggian STP which is treating 10 MGD water (avg.), nonetheless, the present request of tertiary treated water is 6 MGD. According to new local laws the utilization of tertiary treated water has been made compulsory for all houses having region of 1 channel or more. At present, tertiary treated water is accessible for use in division 1, 4, 5, 6, 7, 9, 12, 15, 16, 18, 19, 20, 21 and 61; while segments 2, 3, 8, 10, 11, 14, 17, 23, 25, 33, 34, 37, 41 and 42 are given the fractional accessibility of the same.

Table 5.1: Data on Treated Water & STP's Data

Year	Municipal Population (Lac)	No of STPs	Capacity of Each STP	Treated Waste Per STP	Primary And Secondary Treatment of Waste Water (MGD)	Tertiary Treatment of Waste Water (MGD)	Mode of Disposal
2019	1128065 (30986: Rural + 1097079 : Urban)	5	3 BRD: 5 MGD, Diggian: 30MGD, Raipur Kalan: 5 MGD, Raipur Khurd : 1.25, Dhanas: 1.65 MGD, Maloya: 5 MGD (Estimate approved but proposal being amended)	Raipur Kalan : 5 MGD on UASB Technology.	57	10	10 MGD Sewerage after Treatment upto tertiary level is pumped back to city for irrigation of lawns & open spaces and the balance after treatment upto secondary level is discharged into Natural Streams

Source: ENVIS CENTRE, Chandigarh

5.2 Tube well & Canal Water

Chandigarh has a population of roughly 10 lakhs today. To cater to the water demand of the population, it requires 493 MLD (108 MGD) water, whereas available supply is only 363 MLD (80 MGD). Thus there is a shortage of about 130 MLD (28 MGD). A major part of water requirement of the city is met by canal water. Canal water supply to the city is approximately 272 MLD (60 MGD).



Water Balance Evaluation of Chandigarh Region, India.

Table 5.2: Data on Tube well & Canal Water (2018-19)

Water Sources Drinking Water									
Year	Open Wells	Tube Wells Deep Shallow	Ponds	Streams	Lakes	Rivers	Canals	Rain Water Rooftop Ground Collection	Traditional KhandisNadisBaoris Tanks
2017-18	-	281 Nos.	-	-	-	-	From Bhakra Main Canal	-	-

Source: ENVIS CENTRE, Chandigarh

5.3 Storm Water

The city has well laid out underground storm water seepage framework. The Storm Water Drainage System has been composed keeping in see the incline of the city i.e. from North West to South East. It was at first intended for a rain force of half inch every hour. Notwithstanding, on account of the expanded green zones/open spaces going under development, the keep running off co-proficient has expanded enormously. This has brought about the over stacking of tempest water seepage framework and thus flooding of low lying pockets in the city. The Corporation had led a study and recognized 35 such pockets. The tempest water waste framework in these pockets has been increased by giving extra lines and street ravines. So as to meet the circumstance of flooding, it had been wanted to expand the principle trunk lines running from North to South. One trunk principle running between part 17 and 18, 21 and 22, 34 and 35, 43 and 44 and releasing in the N-Choe in division 51 has been laid at a cost of about Rs.2 crores. To expand the waste framework extra lines have been given in division 7, 8, 15, 24, 28, V3 street isolating part 34 and 44, 38, 41. Extra lines have additionally been given on street prompting railroad station. Around 500 vertical street ravines have been given to build the admission of water in the tempest water lines. The tempest water channels have likewise been given in Rehabilitation state Maloya, Janta and Kumhar Colony segment 25.

Table 5.3 Data on Storm Water (2018-19)

Year	Sectors With Planned Drainage System	Sectors With Originally Planned Drainage System	Sectors With Modified Planned Drainage System	Length of Storm Water Drainage (KM)
2007	1 To 56 Sectors	1 To 56 Sectors	-	
2008	1 To 56 Sectors	1 To 56 Sectors	-	
2009	1 To 56 Sectors	1 To 56 Sectors	-	713
2010	1 To 56 Sectors	1 To 56 Sectors	-	
2011	1 To 56 Sectors	1 To 56 Sectors	-	715 Approx.

2012	1 To 56 Sectors, 61 & 63 Sector	1 To 56 Sectors	1 To 56 Sectors	720
2013	1 To 56 Sectors, 61 & 63 Sector	1 To 56 Sectors	1 To 56 Sectors	722
2014	1 To 56 Sectors, 61 & 63 Sector	1 To 56 Sectors	1 To 56 Sectors	1030
2015	1 To 56 Sectors, 61 & 63 Sector	1 To 56 Sectors	1 To 56 Sectors	1030
2016	1 To 56 Sectors, 61 & 63 Sector	1 To 56 Sectors	1 To 56 Sectors	1050
2017	1 To 56 Sectors, 61 & 63 Sector	1 To 56 Sectors	1 To 56 Sectors	1050
2018	1 To 56 Sectors, 61 & 63 Sector	1 To 56 Sectors	1 To 56 Sectors	1060

Source: ENVIS CENTRE, Chandigarh

Chandigarh has an aggregate rain water collecting limit of over 70% of the aggregate land region. The aggregate limit of water that would be accessible for energize every year is: 58 sq. km (area) x 1059.3 (rainfall) x 0.5 (rainfall coefficient) = 30,720 million litres.

Table 5.4: Area wise Storm water (2018-2019)

Area	Storm Water
From Roads	15.89 sq. km
From the Rooftop of Residential area	30.19 sq. km
From Public and Institutional Buildings	7.94 sq. km
From Shopping area	3.97 sq. km

Source: ENVIS CENTRE, Chandigarh

5.4 Rainfall Data

Rainfall data of Chandigarh union territory compiled from the Daily report of the Meteorological centre, Sector 39-C, Chandigarh.

Table 5.5: Data on Rainfall 2016

Year	Month	No of Rainy Days	Total Rainfall During The Month (mm)
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Year	Month	No of Rainy Days	Total Rainfall During The Month (mm)
2016	January	5	2.92
2016	February	3	5.08
2016	March	9	29.34
2016	April	9	6.8
2016	May	9	12.77
2016	June	17	99.83
2016	July	28	135.64
2016	August	25	100.96
2016	September	8	17.06
2016	October	0	0
2016	November	0	0
2016	December	1	1.89

Source: ENVIS CENTRE, Chandigarh

Table 5.6: Yearly values of Rainfall 2016

Yearly Values	Rainfall in mm
Average Value	34.35 mm
Maximum Value	135.64 mm
Minimum Value	0
Standard Deviation	48.42

Table 5.7: Data on Rainfall 2017

Year	Month	No of Rainy Days	Total Rainfall During The Month (mm)
2017	January	8	29.94
2017	February	2	11.36
2017	March	4	12.64
2017	April	6	16.88
2017	May	3	10.76
2017	June	9	33.57
2017	July	27	73.71
2017	August	22	51.33
2017	September	6	17.78

Year	Month	No of Rainy Days	Total Rainfall During The Month (mm)
2017	October	0	0
2017	November	0	0
2017	December	3	17.83

Source: ENVIS CENTRE, Chandigarh

Table 5.8: Yearly values of Rainfall 2017

Yearly Values	Rainfall in mm
Average Value	22.98 mm
Maximum Value	73.71 mm
Minimum Value	0
Standard Deviation	21.48

Table 5.9: Data on Rainfall 2018

Year	Month	No of Rainy Days	Total Rainfall During The Month (mm)
2018	January	1	4.86
2018	February	3	14.95
2018	March	3	3.68
2018	April	15	15.28
2018	May	4	9.15
2018	June	15	42.42
2018	July	23	145.30
2018	August	28	112.21
2018	September	15	99.36
2018	October	2	3.3
2018	November	2	3.5
2018	December	2	7.9

Source: ENVIS CENTRE, Chandigarh

Table 5.10: Yearly values of Rainfall 2018

Yearly Values	Rainfall in mm
Average Value	38.49 mm
Maximum Value	145.3 mm
Minimum Value	3.3 mm
Standard Deviation	50.68

Total rainfall for 2016 = 412.29 mm

Total rainfall for 2017 = 275.8 mm

Total rainfall for 2018 = 461.91 mm

Average total rainfall for 3 years = 383.33 mm

Average Maximum Value for 3 years = 118.21mm

Average Standard Deviation = 14.63

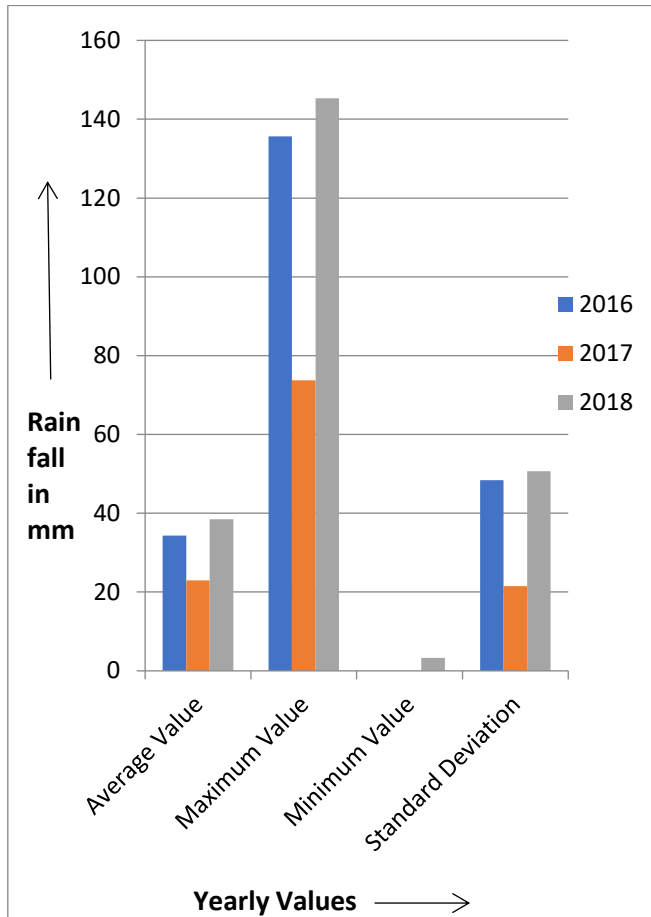


Figure 5.1: Yearly rainfall values in mm

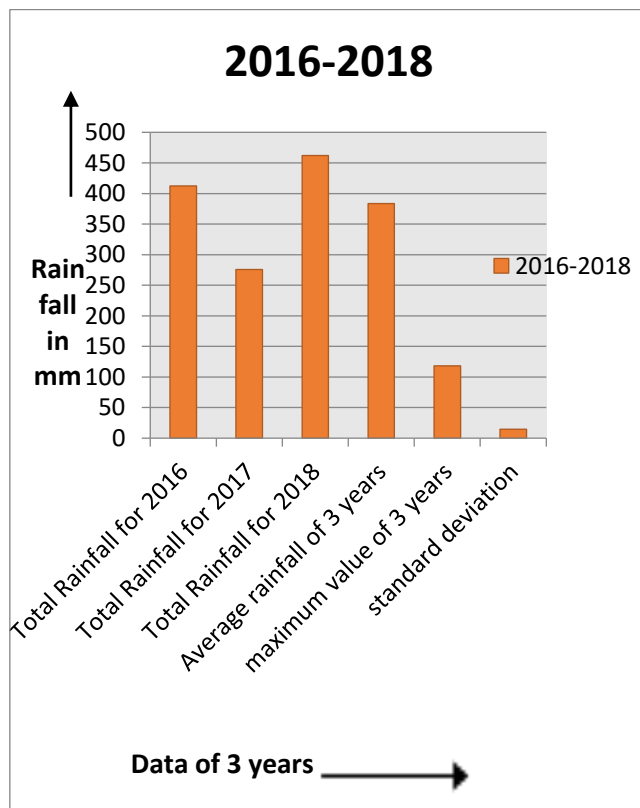


Figure 5.2: Data Analysis of 2016-2018



Figure 5.3: Ordinary Rain Gauge



Figure 5.4: Ordinary Rain Gauge setup area



Figure 5.5: Self-recording Rain Gauge



Figure 5.6: Self-recording Rain Gauge with recording meter

1. ENVIS Centre, Department of Environment, Chandigarh Administration, Paryavaran Bhawan, Chandigarh.
2. Storm water drainage system, Municipal Corporation, Public Health Division No. 4, Government of India, Chandigarh.

VI. RESULTS AND DISCUSSION

6.1 Recharge by Rainfall

Recharge from rainfall during monsoon = 1610 ham
 Recharge from rainfall during non-monsoon = 530 ham
 Recharge from other sources during monsoon = 120 ham
 Recharge from other sources during non-monsoon = 110 ham
 Total annual ground water recharge = 2255 ham
 Natural Discharge during non-monsoon = 230 ham
 Net ground water availability annually = 2160 ham

6.2 Recharge by Canals

Chandigarh has a population of roughly 10 lakhs today. To cater to the water demand of the population, it requires 493 MLD (108 MGD) water, whereas available supply is only 363 MLD (80 MGD). Thus there is a shortage of about 130 MLD (28 MGD). A major part of water requirement of the city is met by canal water. Canal water supply to the city is approximately 272 MLD (60 MGD).

6.3 Recharge by field Irrigation

There are 37 irrigation tube wells managed by UT Chandigarh Administration in the various villages of the city. The depth of these wells is in the range of 180 m-250 m. These tube wells tap confined aquifers below 78 m from ground level. The annual unit draft is 21.74 hectare meters (hams) and gross draft was 804 hams (8.04 MCM). There are 239 tube wells for drinking water supply to the rural and urban population. These tube wells tap confined aquifers below 90 m from ground level. The depth of these wells ranges from 200-300 m. The average unit well draft is 25.15 hams. The annual draft is 4401 hectare meters (44.01 MCM).

6.4 Drought

For each type of minor irrigation works, the draft was calculated by multiplying the number of minor irrigation work with the drafting capacity. Thus, the annual drought values range for various years are as follows:

- For the year 2016, the value is 25 million cubic meters.
 - For the year 2017, the value 27.52 million cubic meters.
 - For the year 2018, the value 25.44 million cubic meters.
- The total drought was found out by summing up the drafts for various types of minor irrigation works i.e. 25.96 million cubic meters.

6.5 Water Balance

For the water balance of the Chandigarh city, we can apply the formula:

$$\text{Water Balance} = R - D * 10^6 \text{ M}^3 \dots\dots\dots 6.1$$

References

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Water Balance Evaluation of Chandigarh Region, India.

Table 6.1: Water Balance for Chandigarh City.

Area	Annual Recharge (10 ⁶ M ³)				Annual Drought (10 ⁶ M ³)			Average annual Drought (10 ⁶ M ³)	Water Balance = R - D * 10 ⁶ M ³
	Recharge by rainfall	Recharge by Canals	Recharge by field Irrigation	Total Recharge (R)	For year 2016	For year 2017	For year 2018		
Chandigarh	22.55	31.57	46.18	100.3	25.0	27.52	25.44	25.96	74.34

VII. CONCLUSION

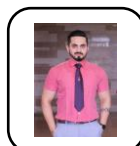
- From this study, we get the results related to water balance by taking proper readings, collecting data from different environmental departments.
- For the proper distribution of system, we have to construct tanks for the storage of waste water and storm water and then apply double plumbing system. For each and every house in the city and for newly constructed flats in the tricity, we have to construct a system like this.
- From table 6.1, we calculated the results related to rainfall recharge, canals, irrigation, droughts and from that results we came to know about the existence of water in the city and future requirements.
- For the future purpose, as water demand is rising day by day and expected population of Chandigarh in 2021 will be 11.60 lakhs, we have to harvest the surface water by water storage and then apply double plumbing by providing separate pipelines of treated storm water and waste water, so that we can meet our demand in future related to water.
- In this study, we are focused to implement double plumbing system, which we are going to consider our case study and we will implement this study on some of the newly constructed towers, buildings inside or nearby Chandigarh and we will find out results related to it.

REFERENCES

- BEEK, K.J. (1978). "Land evaluation for agricultural development ILRI." Netherlands Publication, 23, 333.
- BRINKMAN, R. AND SYMTHU, A. J. (1973). "Land evaluation for rural purposes." ILRI, Netherlands, publication, 17, 116.
- CHELLAPPA, L. (1988). "Morphology and development of land and water resources." Pudukottai and Thanjavur districts.
- CHINNAMANI, S. AND SAKTHIVADVEL, R. (1981). "An Integrated study of hydrology of the Bhavani Basin. Unpublished project report submitted to the Tamilnadu." Electricity Board, Government of Tamilnadu.
- GANDHIMATHI, M. (1988). "Water balance, soil and soil moisture conditions for sustained growth of paddy in Thanjavur district." Tamilnadu, Unpublished M.Phil dissertation submitted to Bharathidasan University, Tiruchirappalli.
- GAUTAM, N.C. AND NARAYAN, L.R.A. (1982). "Suggested National land use/ land cover classification system for India using Remote Sensing Techniques." Pink Publishing House. Mathura, 23.
- HARGREAVES, G.H. (1968). "Consumptive use derived from evaporation Pan data." Jour. Irrigation and Drainage Division, 97-105.
- JOICE, SWAROOPA RANI (1985). "Water balance, water resources and cropping pattern." Coimbatore district, Tamilnadu.

- NAGESWARA RAO, K., AND VAIDYANADHAN, R. (1981). "Land use capability studies from aerial photointerpretation." A case study of Krishna delta, India. Geogra.Revies of India, Calcutta, 43(3), 226-236.
- OBI REDDY, G.P. (1995). "Applied geological study of land and water resources for sustained land use development of Anantapur district, A.P., India." Using Remote Sensing Techniques. Ph.D thesis submitted to S.K. University.
- PENNMANN, H.I. (1956). "Estimating evaporation. Trans. Ameri. Geophys." Union, 31 (1), 43-46.
- RADHA KRISHNA, B. P., DUSAN, D. AND PALIMQUIST, W.N. (1974). "Ground water studies." Publi.No.150, Govt. of Karnataka, Bangalore.
- RAGHAVASWAMY, V. AND VAIDYANADHAN, R. (1980). "Morphology and land systems of part of Visakhapatnam district Andhra Pradesh from air photo studies." Jour. Indi. Sci. Photointer and Remote Sensing, 8(1), 9-21.
- SAMBASIVA RAO, M. AND RAJESWARI, M. (1985). "Morphology and evolution of Tamilnadu river basin." Sixth 70 annual conference of Institute of Indian Geographers, Dept., of Geography, S.V. University, Tirupathi.
- SUBRAHMANYAM, V.P. (1983). "Some aspects of hydroclimatology and water balance of occurrence of drought in dry climatic zones of India." Bull. Internat. Assn. Sci. Hydro. (IUGG), 3, 31-37.
- SUBRAHMANYAM, V.P. AND MURTHY, P.S.N. (1968). "Ecoclimatology of the Tropics with special reference to India. Proce. Symp. on Recent advance in Tropical Ecology." Varanasi, 67-86.
- TIWARI, P.S. AND MISHRA, R.R. (1976). "Identification of watersheds for integrated rural development." All India Symposium on Resource development and Planning. Dept., of Geography, University of Madras, 71
- THORNTHWAITE, C.W. AND MATHER, J.R. (1955). "The water balance. Publication in Climatology." Lab. of climatology, Centerton, (NJ), 8(1), 104.
- U.S. GEOLOGICAL SURVEY (1977). "Office of water data coordination, National Hand Book of recommended methods for water data acquisition." Washington D.C.
- VAN BAVEL, C.H.M. (1966). "Potential evaporation." The Combination concept and its experimental verification. 2, 455-467.
- M. A. Alam, K. Rajat and S. Janmeet (2016). "Water Balance Study of semi-arid region – a case study". International Journal of Engineering Sciences and research Technology, 5(12), 1007-1013.
- C. Dakshinamurthi, Michael, A. M., and Shri Mohan (2001). "Theory and physics of seepage losses from unlined channels". Water resources of India and their utilization in Agriculture, water technology centre, I.A.R.I., New Delhi, 1(1), 32-37.
- Report of the ground water resource estimation committee (2017). Ministry of Water Resources, River Development & Ganga Rejuvenation Government of India.

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