IMPACT OF ATATURK DAM ON REGIONAL RAINFALL

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To my lovely family …

ABSTRACT

Many natural resources are more often than not seasonal or at least depend on some certain environmental factors for abundance fluctuation; one of these important natural resources is water. Hence, it becomes necessary that man must find ingenious ways of harnessing such a critical natural resource for various activities while taking its conservation for continued availability seriously. Dams have become very important infrastructures for meeting man’s various needs ranging from electricity generation through hydro-electric power stations, irrigation services for farmlands, water resource conservation, etc. While dams have proven quite effective in the conservation of water and sometimes regulating amount of available water in some specific geographical areas, care must be taken such that the natural environmental cycles are not largely affected or offset. Since, climate variation is expected to be somewhat progressive and sequential for fairly accurate meteorological predictions, it therefore follows that critical man-initiated activities which could cause large offsets on the environment and consequently climate would render meteorological predictions quite inaccurate and useless in many instances. In order for experts to continue to realize reasonably accurate climate predictions, man-initiated activities such as dam construction and influence should be asseced to rearise progressive changes either positive or negative to our environment. Furthermore, where many arguments prevail for the hazardous effects of dam construction and continued running on the environment, there exists many counter-arguments trying to downplay the significance of dam projects on rainfall change. This work aims to review the place of dam projects in relation to environmental impact; particularly, rainfall changes using the famous Ataturk dam as a case study. The research explores various important literatures presenting critical investigations on the effect of dams for the support or termination of such projects in relation to adverse effects on the environment. More important is that we collect some important data on the Ataturk dam region, with which we provide analysis on the dam’s impact on a critical climatological parameter, rainfall.

Keywords: Ataturk dam, rainfall change, environmental impact, analysis, region

ÖZET

Birçok doğal kaynak mevsimsel değildir veya çevresel faktörlein değişim miktarınabağlıdır.Bu önemli doğal kaynaklardan biri sudur. Bu nedenle, insanların çeşitli faaliyetleri için böylesine kritik bir doğal kaynağı kullanmanın akılcı yollarının bulunması ve korunmasını ciddiye almak gerekmektedir. Barajlar, insanların elektrik enerjisi üretiminden hidroelektrik santrallerinde, tarım arazileri için sulama hizmetlerinde, su kaynaklarının korunması gibi çeşitli ihtiyaçlarını karşılamak için çok önemli yapılar haline gelmiştir. Barajların suyu koruması ve bazen mevcut miktarın düzenlenmesi bakımından oldukça etkili olduğu kanıtlanmış olsa da, bazı belirli coğrafi bölgelerde, su doğal çevresel döngüleri büyük oranda etkilenmemesi veya dengelenmesiiçin özen gösterilmelidir.İklim değişikliğinin oldukça doğru meteorolojik tahminler için biraz ilerici ve ardışık olması beklendiğinden, çevre ve dolayısıyla iklim üzerinde büyük sapmalara neden olabilecek, insanın başlattığı kritik faaliyetlerin, meteorolojik öngörmeleri birçok durumda oldukça yanlış ve kullanışsız hale getireceği izlenimini vermektedir.Uzmanların akla uygun şekilde doğru iklim tahminleri gerçekleştirmeye devam etmeleri için, baraj inşaatı ve nüfuz gibi insan tarafından başlatılan faaliyetler, çevremize olumlu ya da olumsuz ilerleyici değişiklikleri sağlamak için yapılmalıdır. Dahası barajın inşaatının tehlikeli etkileri ve çevrede sürdürülmeye devam eden bir çok argüman hakim olduğunda, baraj projelerinin yağış değişimine olan önemini küçümseyen çok sayıda karşı görüş vardır. Bu çalışma, özellikle ünlü Atatürk Barajı’nı kullanarak meydana gelen yağış değişiklikleri hakkında bir vaka çalışması olarak, baraj projelerinin çevresel etki ile ilişkili yerini gözden geçirmeyi amaçlamaktadır. Araştırma, bu tür projelerin desteklenmesi veya feshine etkisi üzerine eleştirel araştırmalar yapan çeşitli önemli literatürleri araştırmaktadır. Daha önemlisi, Atatürk Barajı bölgesi ile ilgili bazı önemli veriler toplamak ve barajın önemli bir iklim parametresi olan yağış üzerine olan etkisini analiz etmeyi hedeflemektedir..

AnahtarKelimeler: Atatürk Barajı, yağış değişimleri, çevresel etki, analiz, bölge

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CHAPTER 1

INTRODUCTION

Dams are man-made reservoirs for collecting and storing up water for various purposes. Dam construction is one of man's direct responses to the problem of water conservation and resource management. This practice dates several decades back. Such projects have proven quite effective for achieving many activities such as power generation through hydro-electric power plants, irrigation of farmlands, flood control, domestic water provision, sediment control, river navigation, etc. Dams allow the continued compensation for fluctuations in water availability. Dam projects are crucial to the developments of many countries, along with many economic and domestic benefits therein. More importantly, demand for water is ever on the increase in many regions and countries. Also, we would agree that save air and land, water ranks next as perhaps the most important natural resource. Research has shown that in the past few centuries, man has over-exploited freshwater resources resulting in an increase up to a factor of 35. More alarming is that the exploitation of freshwater resources is anticipated to increase even further by around 3% annually; this is coming as no much surprise with the world's current estimated population of almost 6 billion, and with an average annual growing rate of roughly 90 million.

However, the amount of available freshwater resources is not continuously infinite, and even worse is irregularly distributed in many regions. In countries with sophisticated water conservation, recycling and management facilities, addition increase in water demand can be curtailed. Conversely, in areas where such infrastructure do not exist, water availability may dwindle and pose both short and long term domestic, economic and social hardships to residents. In this case, it is not uncommon for water demand to grow continuously, especially out of perpetual population increase. Hence, the impact of dam projects cannot be over-emphasized in addressing impending hardships. More important is that inconsistencies in weather and climate patterns impact river runoffs, resulting in flooding (Kundu & Olang, 2012; Sayama et al., 2015). Dams can be used to store up water in times of excess, preventing disastrous events such as flooding which destroy lives and damage invaluable properties; with such dam conserved water made available during periods of scarcity (Keller et al., 2000; Mijinyawa & Srsquo, 2008).

In the distant past, many of the existent dams were single-purpose. However, technology and ever-broadening man activities are changing events as there are now many multi-purpose dams in existence today. Statistics show that irrigation use is by far the single motivation for dam construction; within the single-purpose dam framework, staggering 48% of such are for irrigation purpose (Amirsayafi, 2015). Hydro-electric power generation comes in second with 17% of such dams (Biswas, 2015). Generally, the generation capacity of hydro-electric power stations depends on the quantity of flow and water head. As a rough heuristic, the head is more often than not the height of a dam. One of the motivations for the construction hydro-electric power stations is renewable nature and 'environment friendliness', fostering little danger resulting from combustion emissions as observable in thermal and coal power stations (Bagher, 2015). Also, associated cost of cleaning up residues from power generation process is non-existent. Another important motivation for hydro-electric power station is that water can be stored up during periods of low energy demand; however, quickly released for fast generation of addition energy during peak periods. Water is also an important resource for many of human domestic activities. Critically, much of the rain that get to the earth surface fall on seas and rivers, while most of the part that fall on land surface is lost to runoffs (Otti & Ezenwaji, 2013). It is estimated that only a very small percentage gets to refill groundwater. Hence, dams play a major role in water conservation for meeting the somewhat ever increasing water resource demand for domestic purposes. Also, to compensate for instability in hydrologic cycles for timely rain precipitation, dams can suffice for consistent water availability during periods of shortages. Another area for which dams are quite usefulness is inland navigation (transportation). This is evident in that inevitable constraints on river conditions such rate of flow, water level, inconsistent channels introduced by sedimentation and erosion make river navigation much difficult. The realization of working inland navigation frameworks relies on properly planned basins outlines which are supported by dams (Frigo & Bleninger, 2015; Mihic et al., 2012). The benefits of inland navigation frameworks as opposed to road include opportunity to accommodate larger cargoes, safety, fuel savings, etc.

1.1 Contributions of Research

1. In this thesis, we review the place of Ataturk dam realize water resource management, taking into consideration the prospects and setbacks of the approach so far.

2. Also, we re-examine the somewhat very delicate arguments surrounding the dam projects and constructions, in relation to its effectiveness and negative impacts, especially on rainfall. For this purpose we use the Ataturk dam, Anatolia, Turkey as a case study.

3. Furthermore, we provide some analysis on the prediction of environmental impact of the Ataturk dam, using historic data collected on the dam region. Metrics of interest for analysis and forecast the rain precipitation.

1.2 Scope of Research

The scope of this work will be limited to the study of Ataturk dam in relation with environmental factors influencing rainfall. We dive into such an important review by starting from scratch, taking into account the pros and cons of dam projects right from the construction phase to its completion and running phase. Hence, we are able to provide within the work a holistic discussion on the merits and demerits of dam construction and its running. Several factors and literatures are considered within this work to allow for broader perspectives of the issues raised and examined. However, for practical consideration and case study, we consider a very strategic and important dam in Turkey, the Ataturk dam, Anatolia. Also, this research goes further to provide analysis of data collected on the Ataturk dam for the prediction of future influence and impact of the running of the dam on precipitation. For the prediction task, we consider some common tools such as multiple regression modelling. Several modelling experiments are performed to ascertain the effectiveness of the proposed modelling tools for forecasting rainfall precipitation.

1.3 Thesis Overview

The following chapters of thesis present a chronological sequence of the crucial discussions, methods and analysis that have used to achieve the aims of this research.

Chapter two presents relevant literatures and broad discussion on dam construction, and then laying emphasis on the Ataturk dam, Anatolia. Also, geographical situation of the Ataturk is briefly but sufficient discussed such that it allows the comprehension of the importance of this work. Also, some existing arguments in favour of dam construction and against in relation to environment impact are critically reviewed, especially in view of the Ataturk dam.

Chapter three describes the motivations for forecasting climate change, data collection and insights into the various analytical methods or tools used for modelling data. Sufficient discussions are offered on the technical inspirations for considered modelling tools.

Chapter four presents the implementations of the various modelling methods that are used within the work for analysing and forecasting climate precipitation, along with specifics on the parameter settings of all models developed. Also, it presents results, comparisons and discussions of the simulated models in order to ascertain their suitability and effectiveness as modelling tools for forecasting precipitation on the collected data.

A brief recap of the aims of the thesis, summing-up as conclusions the highlights of the research and recommendations based on the findings within the work are presented in chapter five.

CHAPTER 2

LITERATURE REVIEW

2.1 Dam Siting

Siting dams is an important task requiring the considerations of some important factors. Some of the major factors to consider before siting a dam include the kind of dam, ratio of size to storage capacity, catchment, soil properties, closeness, spillway, preservation of environmental life, etc.

It is important that the chosen site has the capability to bear a flood bypass setup. The size of the spillway is a function of the water catchment yield properties and rainfall outline or pattern (Chanson, 2014; Sule et al., 2011). Another critical factor to consider is the topographic profile of the location being considered for siting a dam. It is often desirable that the topographic profile allows the dam construction such that the spillway is a connected part of the dam, as it is crucial that the spillway output is returned to the standard drainage prior to leaving the section (Foster & Walling, 1994; Middelkoop et al., 2001).

The efficiency for storage is another consideration to review when siting a dam. A good site should provide excellent utility and economic prospects for collecting the maximum water for particular soil profile present at the location (Grantham et al., 2014; Wildi, 2010). This is referred to as the storage to excavation ratio. A rule of thumb is that for good sites, the storage to excavation ratio is usually greater than 10 (Beckers et al., 2013). Such ratios are achievable in sites with drainages which are broadly flat; while low ratios are obtained in narrow drainages and steeper land profiles. A hilly land profile may be an alternative in situations where

drainage outlines are not feasible as part of the dam construction.

The quantity of water that is retained at a particular site is largely determined by the landscape profile of the location (Yosef & Asmamaw, 2015). Some of the crucial landscape profiles that significantly determine how much water is retained include a site's longitudinal-wise gradient, cross-section, embankment altitude, supply area, top and base surface areas, etc. (Juszczak et al., 2007) Storage capacity for square or rectangular dams can be 'roughly' estimated using the relation given in Equation 1(Department of Food and Agriculture, 2014).

$$V_C = \frac{[A_t + A_b(\sqrt{A_t A_b})]}{(D/3)} \tag{1}$$

Where, V_C is the total capacity of water retained behind bank, D is the height of water adjoining to the bank, A_t is the top surface area of the dam space, A_b is the base surface area of the dam space. Note that A_t and A_b are in m^2, D is in m, and V_C is in m^3.

Going further, there is a need to evaluate the soil nature or profile of sites being considered for building dams. Some of the important considerations include availability of appropriate materials that can be used for realizing an impermeable bank, availability of sufficient material to realize the specifications of bank required and a secure underground base that is invulnerable and water-tight. An appropriate assessment of underground materials is required to evaluate the aforementioned considerations. A common approach is boring test-pits for evaluation in such sites with emphasis on the bank centre and excavation area (Chitata et al., 2014; Schoonover & Crim, 2015). The outcome of such an assessment is for evaluating gravel or sand deposit, organic contents, extreme thickness of topsoil, clay soil permeability and compatibility, soil content that can be cast for building banks, dense and invulnerable material beneath the centre-axis of the bank for knotting the core-trench into.

Another very critical consideration for a site being considered for dam construction is the assessment of salt deposit, as it is quite useless to construct a dam that mainly retains salty water (Dabrowski & Klerk, 2013; Heydari et al., 2013). Even worse is that continuing evaporation further raises the level of salt concentration of stored water. Some of the quick guides for assessing such a situation is to evaluate dam catchments, drainage outlines and site environ for salt patches. Additionally, runoff waters from such sites can be subjected to salinity test (Oluwadamisi & Eze, 2011).

It is also important to be able to estimate the quantity of water on the average that can be retained by a particular catchment. Generally, a catchment profile of thin soil and scanty vegetation cover would possess a higher water yield as compared to one of thick soil and good vegetation cover. Runoff can be estimated from the formula given in Equation 2 (Luxon & Pius, 2013).

$$Runoff = \frac{A \times R \times Y}{1{,}000} \tag{2}$$

Where, runoff is in megalitres (m^3), A is the area of catchment in km^2, R is the rainfall in mm and Y is the fraction of rainfall converted to runoff as yield.

Determining the yield factor, Y, for local catchments is not easily realizable. Firstly, this parameter changes with location and land use; it also varies from one year to the other. Different approaches have been proposed for empirically evaluation of yield factor, using the annual rainfall and soil characteristics. Figure 2.1 shows the approximate relation between the yield factor and yearly rainfall. For a soil with little permeability, it is expected that the yield factor will be above the line. Conversely, for a soil with high permeability, it is expected that the yield factor is below the line. i.e. Figure 2.1 (Http://agriculture.vic.gov.au/agriculture/farm-management/managing-dams/finding-a-dam-site, 2016).

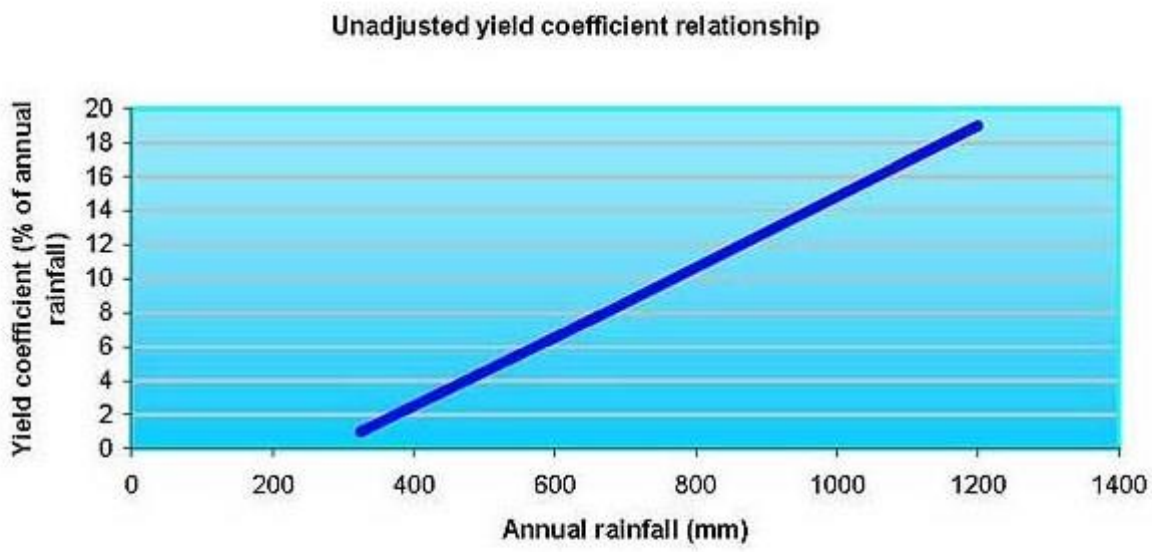

Figure 2.1: Yield factor annual rainfall relationship

Also, for catchments with good vegetation cover, it is expected that the yield factor falls below the line; while for catchments with poor vegetation cover, it is expected that the yield factor falls above the line. Furthermore, the yield factor falls above the line for years with frequent heavy rainfall; while, the yield factor falls below the line for years with scanty rainfalls and fair rainfall. More accurate approaches for predicting yield factor rely on evaluating records showing daily rainfall statistics over a relatively long period of time (Polyakov et al., 2014).

Heavy rainfall is not uncommon in many world regions, resulting in floods from catchments. It is therefore necessary that a dam should be installed with a spillway such that flood flows are run along the dam and then expelled into the original drainage outline so that no damage is brought to the dam. In situations where the drainage system has been poorly designed or has lesser capacity to cope with flood flows, the banks may collapse with the spillway being seriously eroded (Das et al., 2014; Douglas et al., 2008). Going further, in cases where overwhelming flood flows are expected and arrangements for satisfactory spillway is financially impractical; it may suffice to consider an off-stream storage arrangement.

It is critical that siting requirements consider the provision of reasonable freeboard; some allowance should be given to the freeboard in relation to the expected full supply level of the dam, usually around 1m in depth is considered sufficient (Maddrell & Neal, 2012).

2.2 Dam Construction

Dams are constructed usually in four fundamental shapes. Concrete gravity dams depend on its weights for strength against flow stress. The cross-sectional view of the concrete gravity dams gives a triangular impression. The water in the upstream part of the reservoir thrusts against the dam, with the stress neutralized by its weight which pushes downward. Figure 2.2 shows the cross-sectional profile of the Oroville dam, United States. Until 1980, the Oroville dam was the dam with highest embankment in the United States.

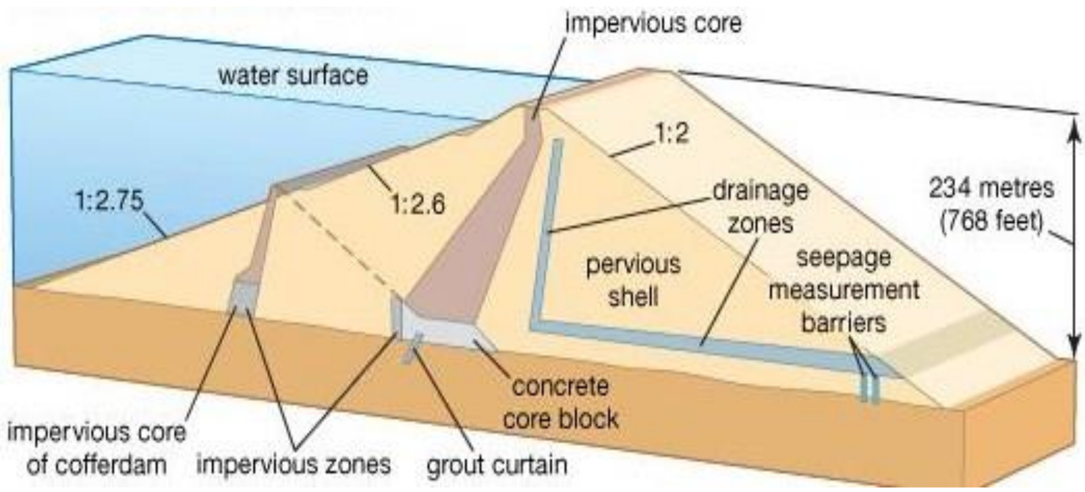

Figure 2.2: Oroville dam profile, United States (www.britannica.com/technology/dam-engineering, n.d.)

Major materials for dam construction include concrete, steel reinforcements, rubber waterstops, siphons, valves, etc. More important is that concrete is obtained from cement, water and additional commonly referred to as aggregates which are primarily sand and gravel. A chemical reaction occurs when cement is mixed with water which makes the concrete turn hard, and in the process producing heat. Hence, there is an initial significant increase in temperature inside the forming concrete such that when it starts to cool, it contracts and fractures, therefore has propensity for leaking when deployed as part of the dam body. In order to reduce this consequence, concrete may be setup at periods the air temperature are considerably low or another cement variant known as low-heat cement may be used. Furthermore, pipes carrying cool water may be installed in the concrete. Also, forming concrete should be installed in thin lifts and in narrow blocks, after which enough time is allowed to elapse in order to permit the concrete to dissipate trapped heat. Engineers on assessing the intended type of dam for construction and design specifications will determine the exact concrete mix (Blanco et al., 2015; Zulkifli et al., 2015).

The designing of a dam would require that the purpose of the dam and the profile of the site be taken into consideration. An overflow dam obstructs the flow of a river, and retained water can be used for power generation, irrigation services or enhancing navigation. An overflow dam has its components so fabricated such that water can be discharged and water level controlled by stacked sluice gates or spillways (Arvandi et al., 2013). Generally, non-overflow dams are used to retain water for domestic purposes, irrigation and seldom for power generation. Non-overflow dams do have spillways too, but its operation is somewhat limited for urgent situations such that water level can be quickly lowered (Joshi et al., 2015). In comparison to overflow dams, systems for discharging stored water in non-overflow dams are considerably limited, and in some cases non-overflow dams are not even installed with any outlet channels or frameworks. At times, water may have to be manually pumped out from non-overflow dams to avoid damage.

Occasionally, a site’s profile determines the type of dam that is suitable for construction. For example, high gorges are suitable for the construction of arch dams, as the arch shape of the structure can provide strength. Also, it is not uncommon that arch dams are constructed across broader gorges where additional effects such as friction acting on the base of the dam introduce further strength and resistance to perturbations. For sites with shallow and broad gorge, the suitable type of dam for construction is the gravity dam. However, if the gravity dam is constructed with curvature, arching action would help strengthen the reservoir when it is sited in a quite elevated and narrower gorge. Dams can be constructed to possess several spans in cases where the riverbed is largely broad, with the various sections of the spans having different engineering features based on the variation of the foundation profile or characteristics. The different spans can be bore on the downstream side with buttresses or elongated curves of several arches. At times, spans of several span dams are built of concrete slabs bore on piers (Mahmoud et al., 2012).

Concrete dams require broad and comprehensive pilot design and practicability assessments of sites proposed for construction. More important is the anticipated amount of water retained by the dam and its value against the overall cost of the project in relation to the expected period (years) of operation, while considering broad environmental variations in determining the dam's optimal dimension and specifications. Generally, numerous factors are put into consideration during the dam construction feasibility studies; and the assessment is more often than not an iterative one. Eventually, a design is selected and tested in relation to all the factors determined through preliminary assessment to ascertain that it satisfies all of them. If the selected design happens to fail any of the factors, a new design which is usually a variation of the earlier one is selected and tested in the same manner to ascertain that it passes on all the factors; this process is repeated until the best design which fails least on all the factors.

The design stage for dams generally involves experts from broad disciplines. These experts usually will comprise geologists, hydrologists, seismologists, geotechnical engineers, structural engineers, mechanical engineers, climatologist, data analysts, etc. Additionally, experts may be required to assess the corrosion rate of concrete and steel materials. In all, a strong teamwork and cooperation among the various experts are required for the successful design and construction of dams, and also to minimize the impact of the different phases of the project on one another; this also largely helps to mitigate professional and work hazards throughout the project development (Kadiri et al., 2014).

Prior to the commencement of a dam construction, the flow from the streambed is blocked or rerouted from the dam site. For fill dams, usually coffer dams are constructed to provisionally hold-off flows or the flows rerouted into another conduit. For massive projects, this setup can be arranged for well in advance before the dam construction commences, and water flow is blocked at the last moment.

The foundations of dams are perhaps one of the most critical construction considerations. Many dams fail due to problems related to the foundations of such dams. The construction of a dam with solid and invulnerable foundations is quite an enormous investment in cost, manpower and time. Firstly, a preliminary assessment of a site meant for dam construction is required. Generally, such an evaluation requires more much complex analysis than the body of the dam itself as the foundation is usually a heterogeneous material characteristic and peculiar to different dam sites. The foundation is required to withstand pressure, be impermeable and resist internal eroding forces.

Many dams are founded on either rock or soft soil, while some are based on partly soft soil and partly on rock. Generally, most low dams are based on soft soil and high dams on rock. Geological studies, seismic evaluations, boreholes, permeability assessments are related to experts who translate them into mechanical analysis for obtaining appropriate structural frameworks. Note that it is standard practice to assume worst case scenarios when putting together final structural frameworks, as this leaves allowance for unforeseen circumstances.

Another critical step is making sure that the foundation of the dam is faultless before concrete would be installed. In the case of fill dams, this is a comprehensive procedure involving excavations, tidying, mending the rock all over the foundation and on the sides of the canyon that outline the ends of the dam (Khosravi et al., 2013; Zhang et al., 2013). Enormous and comprehensive work may be required for some sites in which the foundation is largely susceptible to cracking due to the stress imposed on it by the dam, earthquakes, characteristics of the rock, etc. One of the ways of solving this problem involves the installation of extensive systems of anchor bolts which are plastered into the rock through probable fracture areas. Furthermore, around the period where the foundation of a dam is being laid, it is necessary to install instruments for monitoring critical parameters such as joint movement, groundwater level, prospective seepage, slope movement, seismic profile, etc. Also, the foundation can be fitted with drilled holes for setting up reinforcing steel structures which extend far into the dam such that it can be coupled to the steel inside the first lifts of the reservoir. The motivation is to obtain a reservoir with a “bowl-like” framework that is uniformly invulnerable round its perimeter. This ensures that the dam is not vulnerable and can hold firm even when the reservoir is almost at full capacity.

Earth dams are obvious choice for construction as against rock fill dams in situations where appropriate earth materials are accessible and apposite spillway can be afforded. For earth dams, particular attention must be paid to design, building and maintenance due to highly probable impending internal erosion. The embankment is required to remain invulnerable with hydrostatic stress, and should be composed of materials that are impermeable to trickling (Djarwadi et al., 2014). A homogenous embankment can be realized if the site composes plentiful soil of considerable fineness. Furthermore, it is not uncommon to use both coarse and fine materials for the building of zoned embankments. An impermeable centre core can be obtained by using fine materials which are compacted. The coarse material can be installed on the upstream and downstream parts of the dam to give strength.

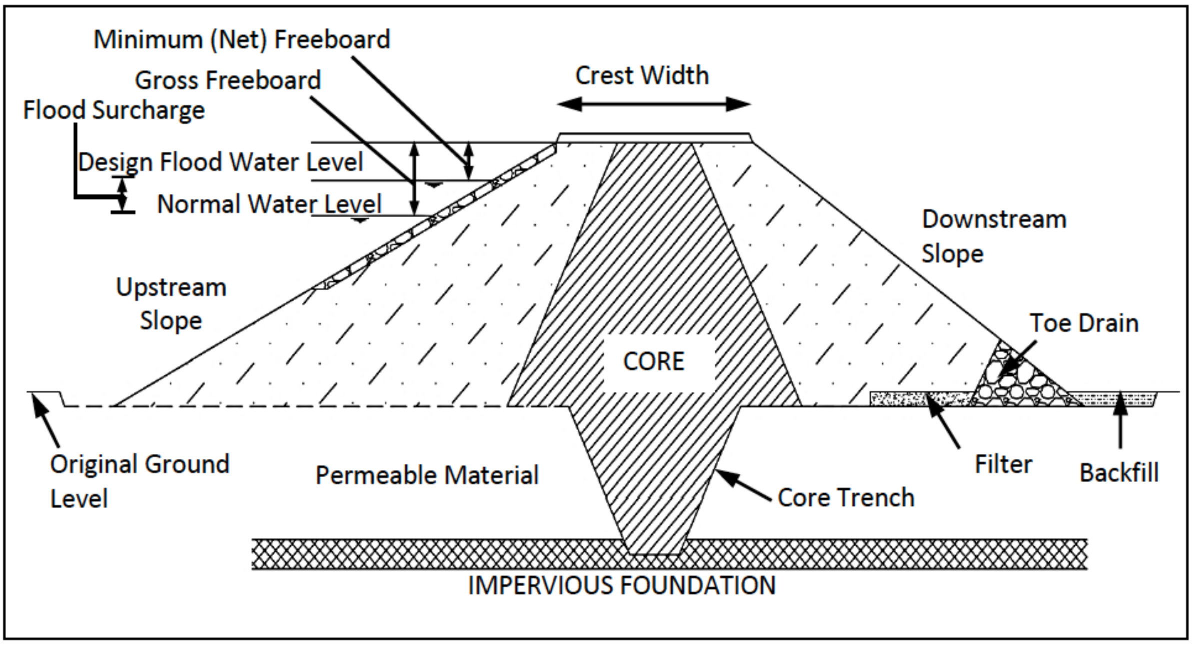

Figure 2.3: Earth dam cross-section profile (Irrigation, 2015)

Also, care must be taken when designing the interface region between the coarse and fine materials. Generally, fillers can be used which allow the trickling of water but resist the displacement of fine particles within the core. Figure 2.3 shows a cross-sectional presentation of a typical earth dam; while Figure 2.4 shows different profile designs for earth dam embankments.

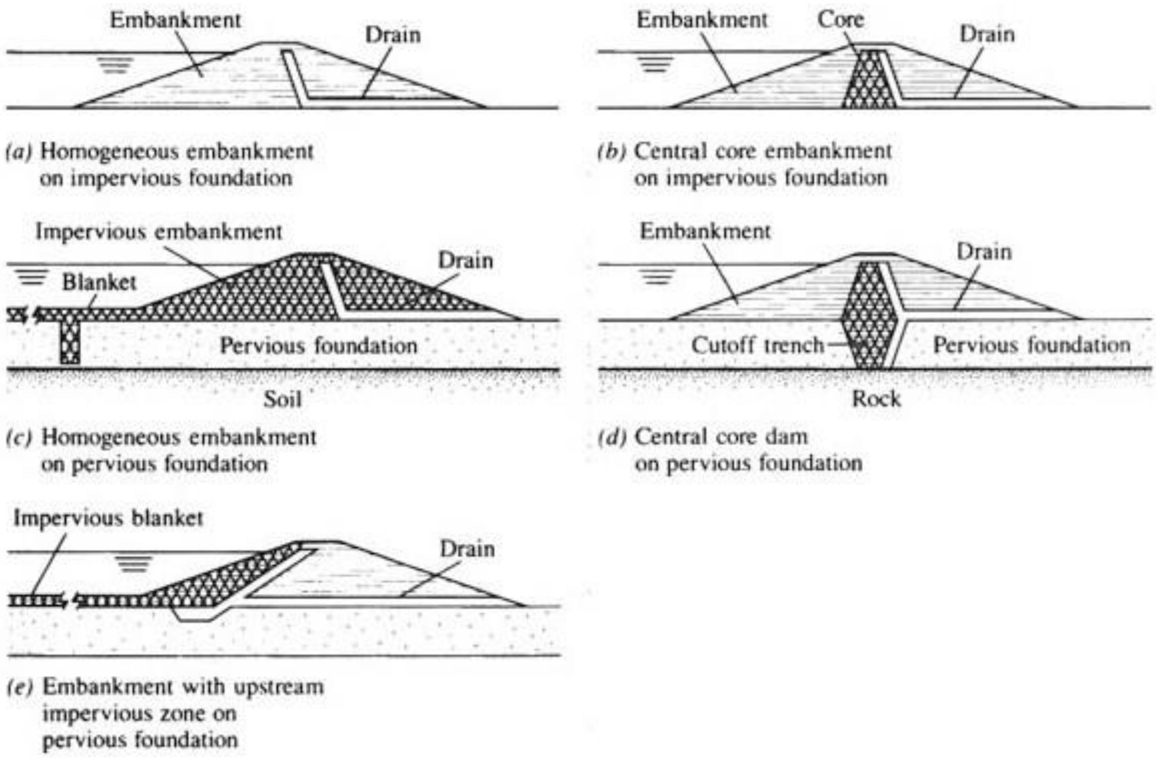

Figure 2.4: Earth dam embankment type (parra.sdsu.edu/roberson_chapter06.html, n.d.)

Wood or steel can be used to make forms, which are placed along the borders of the various dam sections. Reinforcing steels are positioned in the forms and coupled to any adjoining reinforcing steel which was earlier installed. The already mixed concrete can then be poured into the forms. Generally, the height of every lift of concrete is about 1m to 3m, while the dam's length and breadth to be poured as one segment is about 15m. The building continues in this manner with the dam raised segment by segment. It is also possible to have a construction approach where the dam is realized section by section as blocks and then later on connected to adjoining blocks, including steel framework links. In some sense, the procedure is quite similar to a typical building constructions save that dams have considerably smaller internal space. Nevertheless, dams are built with colonnades at various heights so that activities within the dam can be sufficiently monitored. e.g. trickling and movement. Also, outgoing and incoming channels or other compositions pass through concrete dams, making a distinction as compared to fill dams which possess significantly fewer structures penetrating the body of the dam.

The spillway construction requires that some important factors such as rainfall profile, catchment area, site's soil and vegetation profile, etc. An approximate way of evaluating the spillway specification is given in Equation 3 (Stephens, 2010).

$$W = \sqrt{C_A} \tag{3}$$

Where, W is the spillway inlet width (unit in metre) and C_A is the area of catchment (unit in hectares).

Also, it is not uncommon to observe that some dam catchments allow continuous trickle flow. If this situation is allowed to persist, the flow trickling down the spillway will bring an interruption to any existing vegetation stability. This situation can be resolved by intercepting the trickles with a mounted trickle flow pipe, which conveys the trickle to the dam's drainage line.

Going further, when a considerable portion of the dam has been constructed, the filling of the reservoir may commence. This process is achieved in a extremely controlled way so that stress assessment can be carried out and early performance evaluation obtained. Also, a provisional spillway may be built when it is envisaged that the project would extend beyond just one construction season. Generally, the construction project is achieved in phases and each phase is usually duly concluded in itself and is somewhat operational. Also, as additional temporary safety measure the upstream coffer dam which is conventionally designed to retain small flows and rainfall may not be decommissioned till the project has reach a significantly practical and viable stage. In consideration to the type of dam being constructed, the reservoir may not be filled till its basic completion.

As construction progress, other features that render the dam operational are installed as soon as their locality is attained while raising the dam. Some of the final finishing includes erosion and corrosion protection of the upstream part of the dam, installation of instrument along the head of the dam, building of roads, walk-paths, retaining walls, etc. In preparation for the service commissioning of a dam, it is necessary to have in readiness important technical documentations such as operation programs, routine maintenance, safety inspection guidelines, instrument supervising, emergency response guidelines, etc.

2.3 Ataturk Dam and South-Eastern Anatolia Project

The Ataturk dam which is located on the Euphrates River in South-Eastern Turkey, Anatolia, is perhaps one of the most important dams in the whole of Turkey. The Ataturk dam is the biggest among the congregation of 22 dams constructed on the Euphrates as part of the South-Eastern Anatolia project between the 1980s and 1990s for irrigation and electricity generation purposes. After the Lake Tuz and Lake Van, the Ataturk dam comes in line as the third biggest lake in the whole of Turkey (Altinbilek & Tortajada, 2012; Yilmaz, 2006).

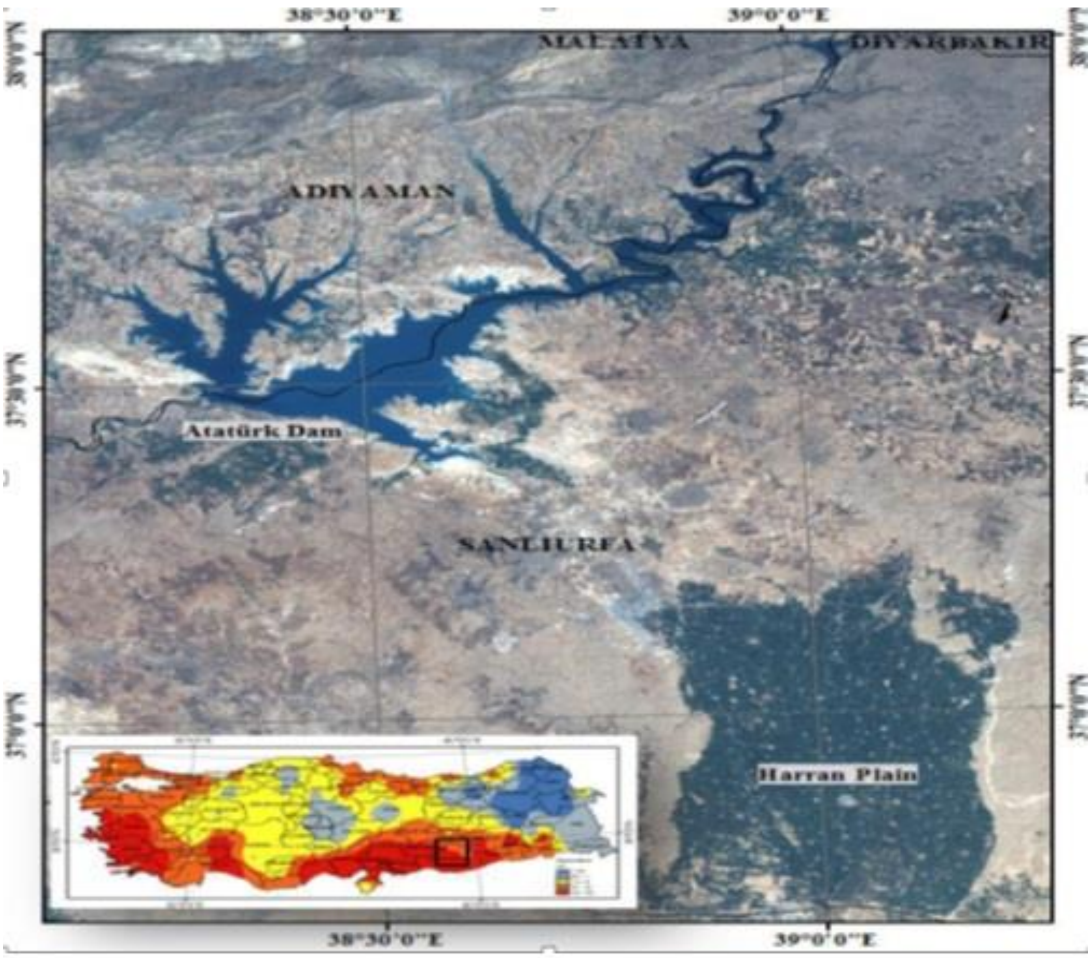

Figure 2.5: Land-satellite image of the region of study, Ataturk dam (Ozcan et al., 2012)

The dam is also undoubtedly one of the biggest earth-and-rock fill dams in the world, with the embankment spanning around 184 m in height and 1820 m in length. It is estimated that the dam has a capacity of 47.8 km^3; the dam project commenced in 1983 and was completed in 1990; an estimated \$1.25 bn was spent on the project (Wadekar, 2014). The water retained by the dam has been used for generating electricity at the Şanlıurfa power station with a capacity of 2.4 GW (Giga-Watt) (Brismar, n.d.). Also, water from the dam has been used for several years for feeding extensive networks of irrigation within the Harran plain and the surrounding. A summary of the variation in the water reserve for the Ataturk dam from 1984 to 2011 is given as the series of land-Satellite snapshots in Figure 2.6, 2.7, 2.8 & 2.9 (Ozcan et al., 2012).

Figure 2.6: Land-satellite image water reserve for Ataturk dam(Ozcan et al., 2012)

Figure 2.7: Land-satellite image water reserve for Ataturk dam (Ozcan et al., 2012)

Figure 2.8: Land-satellite image water reserve for Ataturk dam (Ozcan et al., 2012)

Figure 2.9: Land-satellite image for Ataturk dam (Ozcan et al., 2012)

A study of Figures 2.6, 2.7, 2.8 & 2.9 will show the gradual enlarging of the Ataturk reservoir from its commissioning into service around 1984 to 2011.

Large scale dam projects are motivated by various reasons ranging from irrigation, domestic, industrial, power generation etc. Such projects are usually integral parts of many developing societies. Regional development is never a static feature; more often than not, the priorities of many communities change over time due to various reasons including financial concerns, technological improvements, increased contributions etc. Many other changes that occur during such projects may not be politically motivated; for example, design variations, functions and operations adaptation. Furthermore, unforeseen situations such as water demands, hydroclimatic inconsistencies, etc may make changes in such large projects inevitable (Wadekar, 2014). The Ataturk dam is one of its kinds, a large dam project inspired by regional development scheme and referred to as the south-eastern Anatolia project. The upper region of the Euphrates-Tigris river basin as a reference covers the south-eastern Anatolia project (or GAP). i.e. see Figure 2.10 below.

Figure 2.10: Ataturk dam siting (Brismar, n.d.)

Figure 2.11: Regional siting of GAP region in South-Eastern Turkey (IEA Hydropower Implementing Agreement Annex VIII, 2006)

Perhaps, the most significant project in the south-eastern Anatolia projects is the construction of Ataturk dam. The Ataturk dam construction project lasted around seven years; specifically from 1983 – 1990 (Raikow et al., 1995). As at the time of project initialization, the main motivations for the project were water conservation for domestic use and electricity generation through hydro-power stations. The Ataturk dam was anticipated to have drastic and large developmental impacts on the Anatolia region, being the 20th world largest dam based on height and estimated capacity which are 169 m and 48.7 Mm^3. Figure 2.12 shows Ataturk dam overview; and its cross-sectional profile is shown in Figure 2.13.

Figure 2.12: Ataturk dam overview (IEA Hydropower Implementing Agreement Annex VIII, 2006)

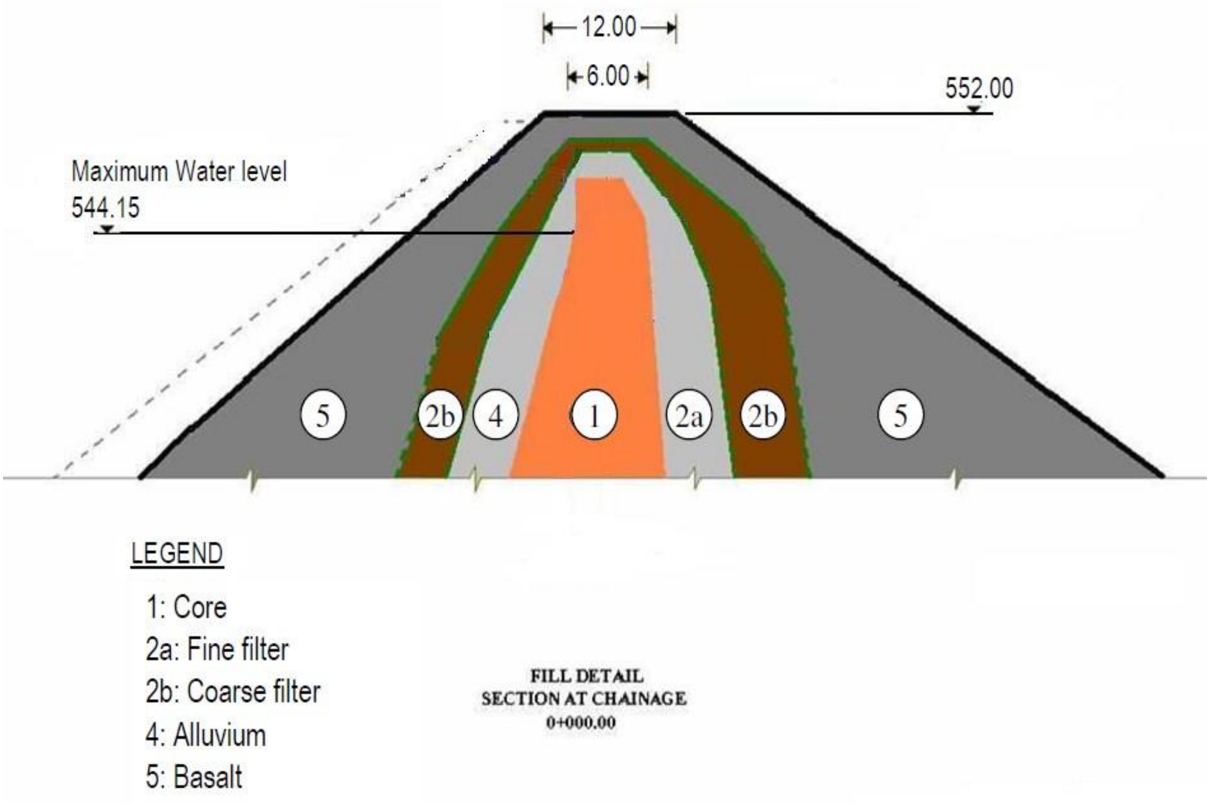

Figure 2.13: Ataturk dam cross-sectional profile (IEA Hydropower Implementing Agreement Annex VIII, 2006)

In the 1970s, the first framework for introducing dams for irrigation and hydro-power appeared from the Turkish State Hydraulic Works. Turkish Euphrates River was schemed out for four dams on lower regions. Over time, the vision for the initially proposed project was expanded within 1970 – 1995. In the end, the GAP was scheme to contain 22 dams, 19 plants and massive space of irrigation cover estimated at 1.7 M hectares. One of the main motivations was to redefine the GAP zone as a modernized region which boasts of large-scale irrigation supported agriculture and related emergent industries. More significant is that the project which was initially named Karabab dam undergone major changes in design specifications and functions over the period 1970 – 1990 (Raikow et al., 1995; Rico et al., 2008)

Also, there were substantial changes in the purpose of the initially proposed dam. In the not too distant past, many literatures began to appear which raise concerns on the environmental impact of such large dam projects. Conversely, due attention has not been given to considerations which allow for relatively moderate changes to be incorporated in such large dam projects; as in accommodation can be made for changes inspired by regional development goals prioritization. Furthermore, there has been a long and somewhat ‘fierce’ debate on the capability of such large-scale dam project to precisely meet the objective(s) for which it was fundamentally initiated; an argument against such consideration is that inevitable situations may hinder the realization of such objective(s). Also, other important factors which motivate such changes include basis of sustainable development, international position, politics etc. In the end such crucial changes are more often than not encountered, and the extent to which the progress of such large-scale dam project is affected is a combination of the various aforementioned factors.

The capacity to employ the Euphrates and Tigris River for power generation was suggested by Mustafa K. Ataturk around 1920. As with many other than developing nations, Turkey realized that in order to join the league of developed countries, the electricity generation capacity ought to be increased. Also, it was along this period that the idea of sandwiching irrigation purpose for improved agricultural capacity was conceived. Around 1960, the Turkish Government saw the possibility of using the south-eastern Anatolia water and land for the earlier conceived development plan (Gana, 2015). Hence, a comprehensive study was initiated for assessing the suitability lower Euphrates River and environs; especially the river segment separating today’s Keban and Ataturk dam. By the end of 1960s, the report describing the feasibility studies covering 22 various amalgamations of four mainstream dams. The report suggested the suitability of Karakaya, Low Golkoy, Karababa dam, Bedir dam and irrigation channels from Middle Karababa dam. The first detailed development plan for the lower Euphrates river was documented in 1970, a project named the Lower Firat Project (Ali, 2012).

The Firat project can be seen as motivated by 5 different national interests. First is the envisaged improvement on agricultural production through large-scale irrigation frameworks. Then, agricultural production was estimated to increase at an annual rate of 4%. Although at that time was already strongly into large-scale agriculture production, it was conceived that further boost can be realized by leveraging on modernized agricultural practices (Hariri et al., 2011; Palumbo & Piroddi, 2001).

The material contribution to the overall economic development of the nation was another critical consideration, as the other more developed regions within Turkish provided economic reliefs and subsidizes to the south-eastern Anatolia region. Hence, it was crucial to embark on development plans that would transform the south-eastern Anatolia region from a heavily reliant region to a productive region. The development plan identified irrigation has the one major area to be leverage on for enormous economic growth, more so that the readily available natural resources within the region are large water bodies, massive land area, good climate and large population (Altinbilek, 2004; Chen et al., 2014).

Furthermore, the incorporation of electricity generation was a feat introduced to justify such a large and costly project as against the initially proposed irrigation purpose. The environment friendly low cost energy generated through hydropower plants could be transported to the western part of the country through the national grid (Akuzum & Cakmak, 1997; Altinbilek & Tortajada, 2012). At that period, Turkey was far from realizing sufficient electricity generation to demand as an estimated 60% of the population lacked assess to electricity. South-eastern Anatolia was then an obvious choice for situating such a project for low cost power generation considering the abundance of water resource and land profile of the region (Autinbilek & Akçakoca, 1997).

The project also initiated the conception of land and water ownership based on the Euphrates river region. There was awareness for surrounding regions to have a treaty for the resolution of conflicting exclusive and joint ownerships. In the end, Turkey gained large influence on the flow of the Euphrates river for servicing their various needs (Isleri, 1970).

The Lower Firat project was combined with other emerging projects meant to enhance agricultural production and electricity generation capacity situated at the Euphrates and Tigirs river basins; the overall project in 1977 was then named Guneydogu Anadolu Projesi which is commonly referred to as ‘GAP’. GAP in 1980 was bundled into a scheme which compose 13 similar projects to facilitate irrigation and power generation; of which 7 of the projects are located on the Euphrates while 6 the remaining 6 are located on the Tigris (Erhan, 1997; Ertunç, 1999). Motivations for such a project were evident as the country struggled to meet 50% demand on electricity. Also, many industries which relied on regular electricity supply had started growing in the western region of the country. More significant is that petroleum price around that period was becoming worrisome; hence, there was the urgent need to consider promising alternatives for power generation.

Turkey in the beginning of the 1980s restructured the GAP such that it became more inclusive of other emerging challenges the country was facing. The direction was to reposition the GAP to foster developments not only in irrigation and electricity generation but as well as other related sectors such as transportation, industrialization, education, social services etc (GAP-RDA., 1997a). One of the key propellants for the revision of the GAP plan was the idea to improve the socio-economic balance in Turkey. As at the, western Turkey seem to be undoubtedly more socially and economically more developed than eastern Turkey; ultimately, the country relied on western Turkey to drive the economy and social development (GAP-RDA, 1997b). Hence, this imbalance and consequently an intense debate with outcry motivated the incorporation of a development plan for eastern Turkey and southern Turkey which were less developed in comparison with other regions. This incorporated plan ensured and emphasized that more national resources were deployed to eastern and southern Turkey in order to 'kick-start' the somewhat crawling socio-economic status of these regions. This act therefore helped to reduce the influx of citizens from eastern and southern Turkey to the western urban region, an emerging population imbalance that would have had dire consequences later on (Harmancioglu et al., 2001). The new development plan was able to reduce the growing political tension in the country from the eastern region over unequal opportunities and quality of living among its citizens. Furthermore, the multifaceted sectoral development plan which was adopted created an enabling environment for the concurrent growth in infrastructure, improved overall working situations of construction workers; hence, the GAP witnessed timely completion of the various phases of the project (Nippon et al., 1990; Rosenberg et al., 1997). Also, the ability to integrate the realization of other objects such as socio-cultural growth aside the initially proposed irrigation purpose inspired some justifications for embarking on such an enormous and cost intensive project as the GAP.

The master plan for the GAP was presented in 1987 to capture fresh objectives, strategies and timelines, and was sealed in 1989. Some of the aims of the GAP master plan include the revolutionizing agricultural practices and production, large-scale mechanized farming, especially on commercial crops (Rosenberg et al., 1997). It was anticipated that the plan would also facilitate other sectors such as forestry, fish farming, livestock etc. Consequently, this should allow growth in employment opportunities, attractions of large pool of technical personnel, standard of living etc (Nippon et al., 1988). Also, such plan was to improve socio-political stability as a result of a sense of inclusiveness by eastern and south Turkey with other more developed regions in Turkey which seem to dominate the political scene as against the eastern region that is largely populated by citizens of Kurdish origin (Nippon et al., 1990).

The Karababa dam proposed in 1970 and which was later on named Ataturk dam was schemed with three choice designs, which are the Low, Middle and High design frameworks. The three different designs were proposed with heights of 85 m, 112 m and 169 m for low, middle and high Karababa dam, respectively. After exhaustive study, the Middle dam was advocated as the High Karababa dam would involve large initial costs. Some other considerations against the High Karabab dam were imminent leakage problems, instability due flooding and reservoir storage capacity that was conceived to be significantly larger than necessary (SPO, 1990; Yaman, 1999). In addition to the Lower Firat project, the Middle Karababa dam was schemed to compose four dams on the lower part of the Euphrates river, which are Karakaya, Low Golkoy, Middle Karababa and Bedir dam. The Middle Karababa dam was schemed to service irrigation needs of the Lower Firat project by covering irrigation on an estimated 0.7 million ha. Urfa-Harran, Lower Mardin, Upper Mardin, Nusaybin-Cizre etc were to benefit from the irrigation servicing capacity of the Middle Karababa project with an estimated 8.6 billion m^3 water volume per year diverted for irrigation. The Middle Karababa dama was also estimated to generate 0.8 Giga-Watt of power; with a major part of generated electricity transported to other regions in Turkey (Kudat, 2000; WCD, 2000). The Middle Karababa dam was anticipated to limit flooding as downstream users can now experience controlled regular flow. Also, there was a conception that such project would facilitate transportation of goods, fishing farming etc.

The GAP plan was reviewed in 1977 to remove the 500 Mega-Watt Golkoy dam project and the inclusion of two turbines and increase of the Karababa dam's height with 57 m to realize the High Karababa dam with a height of 169 m; hence, increasing the capacity of Karababa dam from 0.8 Giga-Watt to 2.1 Giga-Watt. Also, there was an increase in the projected irrigation capacity of the Karababa dam from 0.7 million ha to 0.8 million ha based on the inclusion of two irrigation setups which are Adiyaman-Katha and Baziki-Suruc. The enumerated changes which transformed the earlier proposed Middle Katababa dam to High Karababa dam was seen to therefore to provide more economic benefits and justifiable in relation to expenses. Ultimately, the earlier advocated Middle Karababa dam was discarded for the High Karababa dam (Morvaridi, 2004). Also, the earlier considered Low Golkoy and Bedir dams were rejected. Alternatively, the Berecik dam which was to be located downstream of High Karababa dam was proposed. Towards the end of 1970s, an additional power turbine was installed at the High Karababa dam to increase its electricity capacity from 2.1 Giga Watt to 2.4 Giga Watt. Also, the dam's capacity was increased its reservoir capacity from 5.44 billion m^3 to 19.3 billion m^3. Eventually, the High Karababa dam renamed Ataturk dam after one of the founders of modern Turkey, Mustafa Kemal Ataturk (Eberlein et al., 2010; Kitchen & Ronayne, 2001).

The earlier proposed development master plan for the Euphrates river in view of GAP undergone some changes, as another mainstream dam named Karkamis dam was introduced;

therefore increasing the electricity generation capacity of Karakaya dam from 1.4 Giga Watt to 1.8 Giga Watt. The Ataturk dam construction which commenced in 1983 was finished in 1990, a structure which is hence considered as the most significant of the south-eastern Anatolia project. Then, though the master plan for the GAP had undergone many changes, nevertheless the chief priority for its construction remained irrigation services for increased agricultural production and related activities (Stern, 2004). Ataturk dam alone was estimated to have the capacity to irrigate a 54% of land cover the whole GAP was proposed to irrigate; see Figure 2.14. From the Figure, locations marked with strips are to be irrigated by Ataturk dam, while areas marked with dots are to be irrigated by other water sources. Some crops that top the irrigation concern are cotton, soybeans, corn etc. The irrigation scheme is obviously aimed at facilitating continuous or uninterrupted crop cultivation, even extending well in summer periods (June – Sept). See Figure 2.15 showing the monthly fluctuations in rainfall for Sanliurfa province; data reported was archived from 1931 – 1983 based on recordings from 20 different stations.

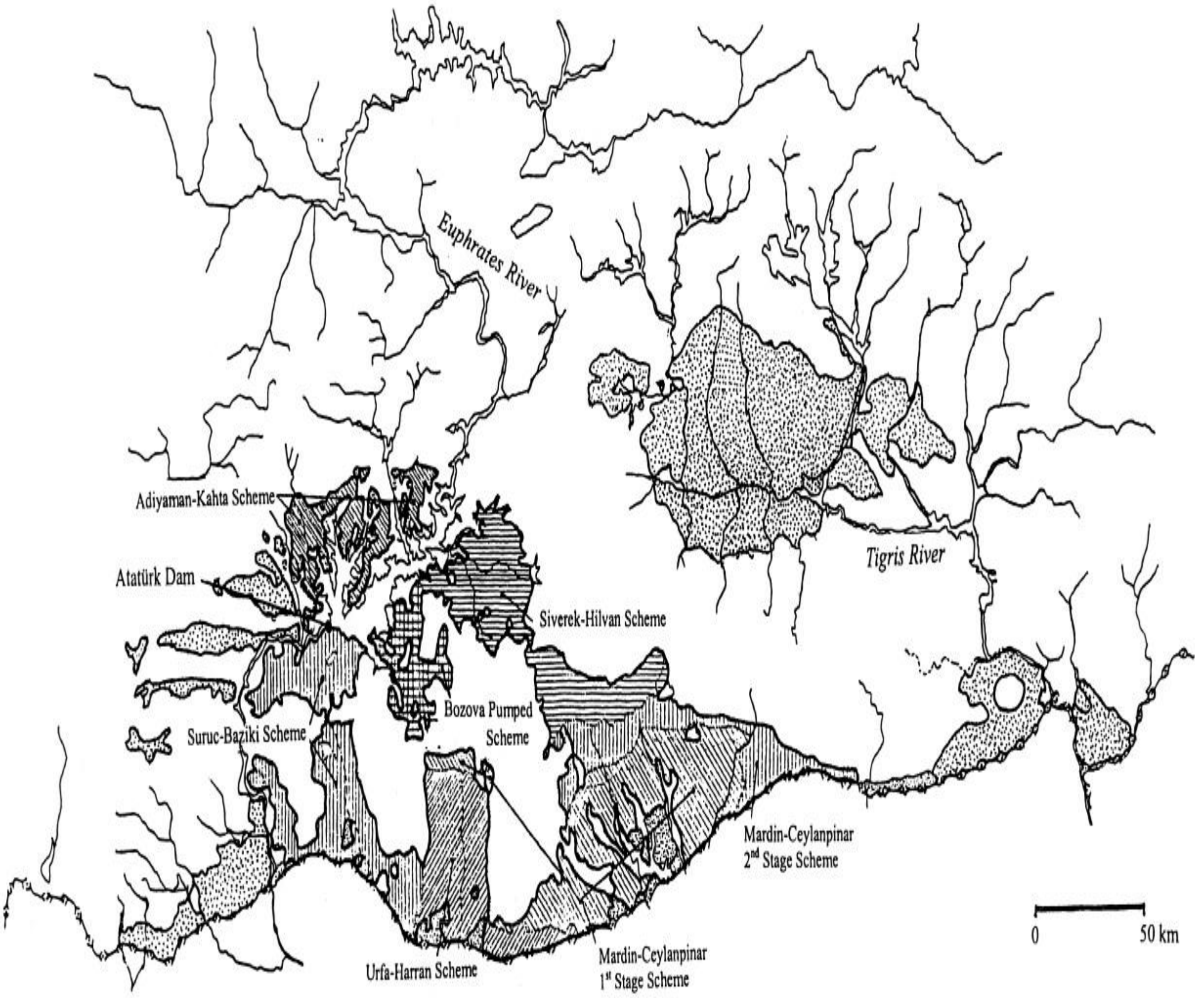

Figure 2.14: Proposed irrigation scheme for the South-Eastern Anatolia region (Brismar, n.d.)

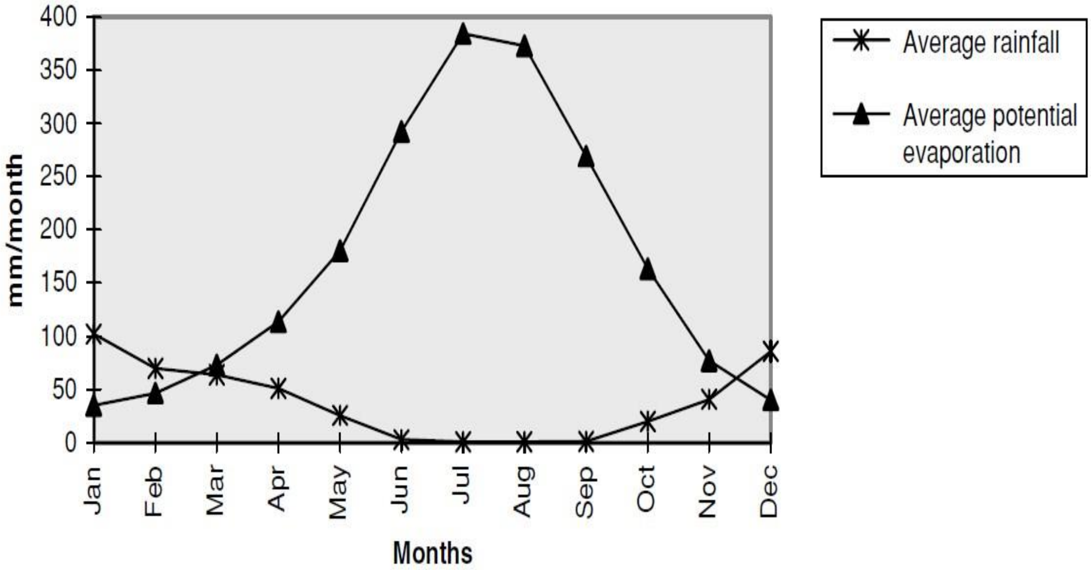

Figure 2.15: Average monthly rainfall fluctuation for the Sanliurfa province (Brismar, n.d.)

Table 2.1 shows the irrigation impact of Ataturk dam over the main crops cultivated in Sanliurfa-Harran region of Turkey. It will be seen that from 1995 to 2003, there was a progressive increase in the area of crop cultivation area irrigated by the Ataturk dam. It is seen that there is an increase in the yield per unit area for areas which were irrigated. This particularly is instrumental to the improved agricultural production. Also, such realized large-scale agricultural production capacity was found to impact revenues made from exports of agricultural products, while concurrently enhancing production capacities of local industries that rely on such products.

Table 2.1: Irrigated area by Ataturk dam on which main crops are cultivated (IEA Hydropower Implementing Agreement Annex VIII, 2006)

Years	**Area (ha)**			
	Net Irrigated	**Cotton**	**Cotton rate (%)**	**Grains**
1995	21, 603	20,613	95	345
1997	46,097	37,925	82	5,051
1999	79,649	62,518	79	15,932
2001	99,046	89,872	91	9,865
2003	98,837	75,427	76	20, 008

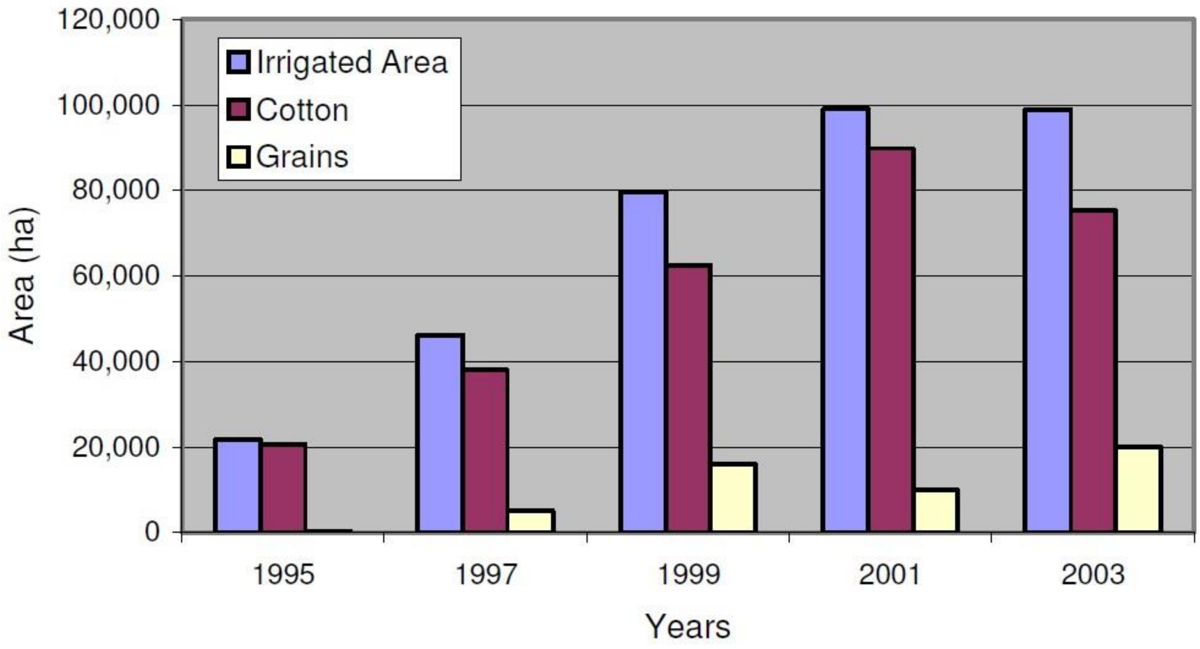

Figure 2.16: Ratios of irrigated land area for main crops by Ataturk dam (IEA HydropowerImplementing Agreement Annex VIII, 2006)

The Ataturk dam installed electricity generation capacity was estimated at 2.4 Giga Watt, representing a staggering 32% of the total electricity generation capacity anticipated from the GAP. The dam was schemed to provide some electricity generation downstream at Berecik and Karkamis. Also, the Ataturk dam was anticipated to facilitate large scale fish farming, as rivers conditions are conventionally unstable and therefore cannot support such large-scale and continuous fish farming. This improved fish farming at such large-scale was deemed to enhance economic activities including export possibilities. Furthermore, other key areas that were identified to be beneficiary include mass tourism spots and recreation locations as a direct presence of the erection of the Ataturk dam. Since the completion of Ataturk dam in 1992, its initially proposed domain (or scope) of influence has gradually been expanded. For example, the irrigation area which initially stood at about 8.8 million ha as at 2001 had been extended to about 9.75 million ha. Also, there was gradual push for the export of electricity generated from Ataturk dam across borders (Al-Ansari & Knutsson, 2011; Warner, 2008). By 1995, Turkey had initiated some energy pacts with neighbouring countries such as Syria, Iraq, Jordan etc. Turkey then went on to benefit from such electricity exports, realizing large revenues from such. There were attempts in 1996 to lay down environmental policies for controlling anticipated problems including erosions along hillside and shores, salt deposition, sedimentation etc such that water quality is not affected.

Ataturk dam's reservoir, referred to as Lake Ataturk which is happens to be the third biggest in Turkey, exceeded by Lake Tuz and Lake Van. The reservoir at full capacity stands at a height 542 m above the mean sea level. The minimum reservoir level for the dam to be operational is 526 m above the mean sea level.

GAP was anticipated to double the irrigated land area in Turkey and raise per capital income in south-eastern Anatolia by 50%. It was also estimated that the project would quadruple gross nationally generated revenue and generate jobs for about 2 million people.

Climate in south-eastern Anatolia, and therefore Ataturk region is averagely cool and slightly rainy winters, placid spring and scorching hot summers; summer temperature can reach 30°C. The average yearly temperature is about 17°C- 19°C; average yearly precipitation is about 473mm; and average yearly humidity is about 48%. As precipitation is weather parameter that varies with attitude, precipitation in the Ataturk region is in the range 300 mm- 1000 mm. Major precipitation is usually observed to be sometime between November-May. Starting from December, it starts snowing; the accumulated snow by then starts melting around April or May. Melting snows and rainfalls can sometimes cumulate to flooding of the area. From Nov-May, there is a high average flow; while from July-Sept, there is minimum flow. Hydrological studies revealed that the Ataturk's dam average annual flow is estimated (Egre & Senecal, 2003).

Dam reservoirs which can be considered as artificial lakes, should allow the development of fish life as it obtains in natural lakes. It should particularly support a vast and diverse aquatic life, and alongside build a platform for leisure activities such as recreational fishing. Over time, Ataturk dam has become quite popular for such aforementioned activities. It is estimated that the annual capacity is 1,000 tons of fish, translating to estimated annual revenue of $1.26 million. Moreover, even when reservoirs situation do not seem to be well capable of sustaining such large-scale fishing farming through continuous reproduction, it is possible to breed fingerlings in dedicated fish hatcheries and later on relocated to the dam's reservoir; a process commonly referred to as fish restocking. An estimate 33 million fingerlings that were bred in DSI Ataturk dedicated fish hatchery have been used for stocking Ataturk dam reservoir since 1992 (Cetin et al., 2000). In following events, sports festivals are organized at Ataturk dam for sports such as swimming and sailing. Also, water transportation has been growing ever since.

In 2000, some group of persons and organizations apprehensive of the construction of Iisu dam on the Tigris River launch massive campaigns as the environmental effects to the completion of the project on south-eastern Turkey. Experts say that had the project been successfully completed, flooding of a large area of the region would have occurred. More important is estimated 183 villages and hamlets would be been submerged. Unfortunately, the Turkish Government lapsed in her responsibility to perform proper studies and liaison with the people of the affected region to generate resettlement plans and other palliates to alleviate the sufferings that may arise from such displacement. This act also strongly convenes international codes of ethics or best practices. Also, another point of apprehension was that the Ilisu dam project was not a newly initiated project but a part of the earlier and highly ambitious initiated GAP. The GAP development plan was launched as extensive project to cover 7 water dams on the Euphrates and 6 on the Tigris. After completion, the GAP was estimated to span 74,000 km^2 and irrigate about 1.7 million ha of land and also useful to service electricity generation (Beaumont, 1996; Kaygusuz, 1999)

One of the many apprehensions of the campaign was based on that the fact that the Ilisu dam was contracted to US and European companies that had requested financial help from their national government agencies. In the end, with much pressure from non-Government Organizations, success was recorded in compelling the concern parties to reach agreements on the resettlement of affect communities in the region; that is, south-eastern Anatolia. Equally important was the resolution to sign pacts with countries which are situated downstream of the Ilisu dam. Primarily, the countries involved which are situated downstream are Syria and Iraq. The agreements reached included that Turkey provided an arrangement upstream for water treatment to ensure the quality of water going down stream. Also, Turkey was made to agree to some terms on the regulation of water flow downstream to Syria and Iraq. The above conditions opened up a new perception of the project, especially regarding Turkey's then strained relationship with the aforementioned neighbouring countries due to the proposed Ilisu dam project. There was also a looming conflict between Syria and Iraq as both countries were apprehensive of the outcome of the water diversion from the Euphrates and Tigris River for the massive proposed dam projects. The negative outcomes of the proposed project were duly dismissed by then by Turkey, stating that the Ilisu dam project pose no serious threats to the neighbouring countries, though there were experts with contradictory beliefs on such claims.

2.3.1 Dams and consequential conflicts

In the last four decades or so, the world has witnessed a massive increase in socio-political contention among states for the ownership and control of territorial waters. This problem has been further fuelled by giant advancement in the concrete technology and structural engineering domain, sparking the possibility of embarking on the construction of large dams. Also, the construction of large scale water transfer frameworks has become relatively plausible by then. It is no doubt that water development schemes can be leveraged on to improve the quality of human life, however, facts that available for many completed large dams suggest that are have been some concealed critical social and environment consequences (Kaygusuz, 1999a). It is however not surprising that many experts are not opposed to the construction of large water dams in view of impacts on environments in which these projects are situated. World Commission on Dams (WCD), an international organization that saddled with the responsibilities of establishing guidelines and globally acceptable best practices for the hydro industry, in relatively recent times (around year 2000), have suggested that though dams have some benefits towards the various human water development schemes, such has often come with unacceptable prices for realizing its benefits; there are many downsides. For example, social impact involved the displacement of people and therefore communities away from downstream, as they are longer guaranteed regular flow and quality water downstream from such large dam projects (Tekeli, 1990).

Particularly, the WCD has been able to recognize the role played by such large water dam projects to raise conflicts among neighbouring countries over the control of such involved water bodies. WCD was able to establish that large dam projects are usually responsible for many changes rivers conditions and its unconventional uses are largely growing. Even more critical is the inevitable diversion of such natural source from local riparian to some new group beneficiaries; this is happens at local or national levels. When this situation is local (regional level), the management is often easier to achieve. However, when such situation happens at national level, the management is not one that is easily achieved; it is not uncommon to find that bring all parties to terms and reaching peaceful resolution are almost impossible. Also, such situation seems to support the transfer or reinforcement of power with the region containing such large water dam projects as against the region downstream, since the region with the water dam now control such water bodies and what the region downstream get of the natural resource (Kaya, 1998). Generally, those largely affected include indigenous communities, minority ethnic groups, subsistence farmers etc; their water and land are annexed, and even worse usually without any sense of adequate compensation for such actions and impending inconvenience as a result. On the other hand, beneficiaries of such large water dams have the propensity to get richer and experience enormous social development; there is rapid growth of agricultural production capacity and industries' local and foreign domain of influence.

Furthermore, the WCD has identified that more often than not, the longer term impacts of such large water dams are not limited to the immediate communities which are downstream; but in the long term, remote communities and even countries may have to contend with consequences of such large-scale water dam projects. Some of the emerging issues identified include agricultural practice, irregular flood patterns, discharge and river flows, diminishing fish stock and quality of water etc (Akpinar & Kaygusuz, 2012).

Dams constructed for irrigation purposes are usually disposed to the considerable reduction of water flow downstream. Often times, the water diverted for irrigation services is never returned to the river. In any case that some water is returned, the water is usually contaminated salts that are washed off irrigated land soils, fertilizers, pesticides etc. Hence, the water returned to the river is considerably polluted with impending effects on the consumers that are situated downstream. Furthermore, when dams are constructed for electricity generation, the management of such dams may pose serious threats to the regularity of flows downstream; hence, imposing a challenge to farmers downstream in predicting the timing of flows to complement their agricultural production requirements. Therefore, communities situated downstream experience hardships due to unpredictable and unreliable water flows and supplies at crucial agricultural production cycles. Also, health problems as a result of the consumption polluted water from various activities that are carried out upstream. In addition, in a situation where water is not solely controlled by a region (or states) but shared by different regions (or states), it is not uncommon that a (or some) state(s) which is (or are) situated upstream may purposefully use water as political weapons; such state(s) have the tendency to impose irregular downstream water flows or even completely shutting it as deem necessary to realize their political ambitions or desires (Akanda et al., 2007).

2.3.2 Politics of water scarcity

There as many a long history of disputes among different regions over control of water resource. However, there are also reports showing that such natural resource has led to the unavoidable corporations of different regions (societies) in managing the water resource for their common good. At local or international fronts, these various societies have had to find peaceful resolutions to the control and management of such shared natural resources, rather than allowing conflicts of interest degenerate to war. In situations where conflicts arise, it is almost never the case that total unavailability of water is responsible. It is obvious that water resource is hardly sufficient to local and remote demands irrespective of the fairness of sharing such a natural resource. Undoubtedly, water is a resource that is locally limited, and what is more apprehensive is quite not the future availability of such resource, but the unequal power feature that persists in such states that compose the affected region.

The European Commission assessing the situation, affirms that conflicts premised on the limited availability of water resource is indeed not genuine, as studies reveal that other factors unrelated to scarcity issues are usually responsible for such conflicts. Some of the highlighted issues include racism, tribal rivalry, ethnic chauvinism etc (Tomanbay, 2000). Also, there is the issue of socio-economic and political domination of one region over the others. Hence, it is seen that water conflict is usually the outcome and not the basis of conflict among neighbouring societies; not only increasing tension that is already in existence but systematically creating new lines of apprehensions. Such situations as discussed above can rapidly result into violence if urgent steps are not taken by aggrieved parties to proffer peaceful resolution. This situation is usually more serious where aggrieved parties are states; there is a high tendency for armed violence to ensue. In fact, in recent times, there seems to some global concern and a growing tendency for armed conflict among countries over the ownership, control and use of territorial waters. In many instances, the water disputes have culminated in a long history of huge anxiety; and some cases, ensuing conflicts; for example, the long history of such tension and conflict on the Euphrates and Tigirs rivers (Kibaroglu & Ünver, 2000). In addition, it is wrong to assume that only adjoining states are involved in such tensions and apprehensions, as there are also histories of tensions between non-adjoining states; for example, Ethiopia and Egypt have records of large threats indicating war on proposed dams on the Blue Nile River.

The particular nature of conflicts and its resolution over water resource control more often than not is dependent on the relative political influence of the aggrieved parties. This situation was subtlety captured by WCD, which stressed that apprehension over trans-boundary rivers more often than not emanate from power imbalances among affected riparian; some states are politically influential enough to dominate others. More significant is that emerging large scale dam project have been increasing the domain of apprehension among aggrieved parties, as some parties can vie for the sole control and use watersheds. WCD stress that dam projects are the single most common source of conflict provoking of water resource, as a state can redirect, hoard, impact water quality such that conflict is usually inevitable from states situated downstream. Also, there seems to be the trend that international concerned organizations are reluctant to affirm unequivocally that large scale dam projects are absolute basis of conflicts. There is also the tendency to comfortably talk of flooding, water pollution, water insufficiency etc as basis of conflicts than admitting that man-initiated activities, of which dams are obviously and largely core causes (Tortajada, 2000). WCD articles also stress that investigated cases of conflicts over water resource reveals that beneath the shallow reasons meant to cover up the actual source of conflict are some anticipated dam projects, which states situated downstream are apprehensive over.

2.3.3 Dam projects on the Euphrates and Tigris rivers and associated conflicts

The Euphrates River has its origin in the North-Eastern Turkey Mountains; quite a number of tributaries ascend before uniting close to Keban to create the popular Euphrates River. Beyond Keban, the river heads south, branching off at Jarablus into Syria. Inside of Syria, other rivers such as Sajur and Balikh merge with it before heading off at Al'Qa'em into Iraq. Afterwards, in the south of Iraq, it then unites with the Tigris River to create the Shatt Al-Arab River. The Shatt Al-Arab River finally ends up around Al-Faw into the Arabian Gulf. History has it that the three co-riparian countries (i.e. Turkey, Syria and Iraq) have for long had apprehensions over the span of the Euphrates and its rate of descent in the three countries. Latest records released by the Government of Iraq gives the length of the Euphrates River at 2,940 km. Also, it was estimated Turkey contain the longest run of the Euphrates, followed by Syria, with Iraq containing the shortest run of the Euphrates River (Balat, 2003; Yuksel, 2006).

Furthermore, it is estimated that less than one-third of the Euphrates River is contained inside of Turkey, around 90% of the water sources from within Turkey. The Euphrates River drainage area is also estimated to be around 444,000 km^2. There has also been dispute over the Euphrates River in respect of the different spans of the river contained by the different countries; there are various formulations of the sharing of the Euphrates River. However, a common feat is that Turkey always leads in sharing terms.

The Tigris, the second most important river relating the three aforementioned countries, has a span of about 1,840 km. Inside of Turkey, the river runs via the south-eastern region for an estimated 400 km, after which it creates a border along Syria for an estimated; it then eventually heads downstream into Iraq. Similarly, there have been disputes among the three countries over the span, drainage area, each country's allocation of the Tigris River. Going by records captured by the Government of Iraq, the drainage area was estimated at 235,000 km^2, with about 45% of it contained within Iraqi's territory (Kaygusuz, 1999b). It is characteristic of the river of have high yearly flow and seasonal inconsistency.

In not too distant past, both Turkey and Iraq have initiated plans on water development plans that rely on the Euphrates and Tigris Rivers, therefore impacting the Rivers and consequently the lives of people those regions. The large Mosul Dam was finished by Iraq sometime in the 1980s. The Mosul Dam has an estimated capacity of 10 billion m^3. Sequel of the completion of the Mosul Dam, the Iraqi Government has also embarked on the erection of a larger dam on the Tigris with an estimated reservoir capacity of 12 billion m^3. Such large scale dam projects initiated by Iraq have purportedly led to the altering of the Tigris River and annihilation of the exceptional ecosystem of Mesopotamia's marshland (Biswas & Tortajada, 2001). A consequence of such large scale dam projects has been contended by many experts has the direct or indirect cause for the displacement of the local Marsh Arabs from the region; this is not too unreasonable in the face of impending hardships as a result of uncertain water resource allocation and control.

On the other hand, records have it that the Turkish Government has constructed 5 large dams along the Euphrates in realization of the south-eastern Anatolia project; more worrisome is that the Turkish Government has been purportedly seeking to initiate some new water development schemes along the upper region of the Tigris River. However, the proposed Ilisu Dam and related electricity generation projects seem to be core interests in the GAP plan associated with the Tigris River. Some concern experts have stressed that if such projects are completed;

estimated 78,000 local (mostly Kurds) people would be displaced. Interestingly, massive global campaigns against such projects have fuelled interests in international organizations, the result being the inability for the project to attract funding. Another Dam, known as the Cizre Dam was proposed to be built downstream and run in union with the Ilisu Dam. This arrangement was anticipated to act as a critical regulatory reservoir such that the highly inconsistency peak power can be evened out, and excess water can be channelled away for irrigation services of surrounding arid lands. Presently, the GAP has about 11 constituent water development projects along the Tigris River basin, out of which 10 projects are situated upstream of Ilisu (Kaygusuz & Sari, 2003). These cascaded of large dam projects has been identified has a key reason for the considerable decrease in the river flow prior to getting to Ilisu.

2.3.4 The South-Eastern Anatolia Project (GAP)

The South-eastern Anatolia project, known in Turkish as Guneydogu Anadolu Projesi (or GAP) has a long history to have created tension in the region where is situated. Concerned countries, Turkey, Syria and Iraq have at one time or the other been engaged in heated political and territorial conflicts over the control and use of the Euphrates and Tigris Rivers. The GAP project was anticipated to compose 14 dams along the Euphrates River and 8 along the Tigris River. The uniqueness of the situation, in which the Euphrates and Tigris Rivers are strategically located, has further fuelled the emerging conflicts. The GAP was initiated in 1977 and anticipated to cover about 9 provinces, spanning about almost 75, 000 km^2. The project was also estimated at $32 billion; hence, making it the largest project the Turkish Government has ever committed itself to and bringing it into the league of largest dam projects in the world. The total execution of the initially proposed GAP project is expected to have realized about 90 dams and 60 hydro-power stations. The total capacity of the hydro-power stations is estimated at 27,000 billion Giga-Watts. Also, it was anticipated that the project would allow irrigation of a large area of land in order to support general agriculture and in particular boost the cultivation of cash crops and improvement of dependent agro-industries (Kibaroglu, 2000). The region about the Ataturk dam was successfully transformed into one of the largest cotton production area in the whole of Turkey. The available records estimates Turkey's financial commitment in respect to the GAP at $14 billion; out of the proposed constituent parts of the GAP, 12 water dams and 6 hydro-power stations have already been completed. Also, estimated 60% of the hydro-power stations are already completed and running, supplying about 15% of the total electricity demand in the whole of Turkey the Table 2.2 below shows the details of constituent parts of the GAP.

Table 2.2: Details of constituent parts of the GAP

Euphrates River	**Tigris River**
Karakaya Dam	Kralkizi Dam
Ataturk Dam	Dicle Dam
Birecik Dam	Batman Dam
Karkamis Dam	Silvan Dam
Gamgazi Dam	Kayseri Dam
Gomikan Dam	Garzan Dam
Kocali Dam	Ilisu Dam
Sirimtas Dam	Cizre Dam
Buyukcay Dam	
Kahta Dam	
Cataltepe Dam	
Hancagiz Dam	
Kayacik Dam	
Kemlin Dam	

The GAP was initially was proposed as nothing more than water development scheme in the south-eastern Anatolia region. However, the GAP transformed into a development plan that was more than only water development plan; over time, roads, schools, hospitals, houses, tourist attraction centres etc have all been built in the region. GAP management body stresses that the incorporation of other projects into the initially proposed GAP reflects the Government's commitment to the social and human development and overall welfare of its citizens (Alp et al., 2010). However, the initialization of the GAP is somewhat questionable in that there was no appropriate consultation with the immediately concerned people. More so, that the GAP was essentially executed without significant involvement of the locals or residents. It is estimated that several thousands of locals were displaced from their homes without appropriate resettlement plans or corresponding compensations. Even worse, quite a number of such displaced locals had to resettle in the slumps of neighbouring regions, without reasonable employment and very low standard of living. Beyond the radical displacement of local residents, there are now emerging concerns over salinisation of lands schemed with irrigation (Kamel et al., 2013). Also, soil erosion is another source of worry. It is estimated that about 7 million ha of irrigated land are under threats of deepening erosion.

From the inception of GAP, the Turkish Government has argued that such a project do not pose any serious threat on neighbouring countries; particularly, Syria and Iraq. While the directly affected neighbouring countries have been swift to admit that they do not oppose Turkey's socio-economic growth by initializing the GAP, there remain very strong concerns as to the impact of the GAP on Euphrates and Tigris rivers downstream low and contamination (Beaumont, 1994). Furthermore, affected countries are apprehensive of the fact that the GAP was a strategic scheme for Turkey to exert some political influence on the region through the control of Euphrates and Tigris rivers.

The details of the GAP show that much of the water to be dammed is for irrigation servicing. As earlier stated, when completed, the GAP is anticipated to provide irrigation for an estimated 1.7 million ha of land. For the Tigris River, studies on the GAP impact estimated that the completed dam projects are to provide irrigation for about 600,000 ha of land. The Iraqi authorities stressed that the GAP irrigation scheme sourced from the Tigris River is estimated to consume 5.8 billion m^3 of water. Also, there are claims that such extremely large diversion for irrigation would cause reduction of the flow of the Tigris along the Syria border to about 66%. Iraqi authorities went further to stress that after accounting for the incoming water flow at Syria, the amount of water reaching Iraq is expected to reduce by about 47% of the initially received amount; that is, without the GAP. Going further, Iraqi authorities have affirmed that such flow reduction will greatly impact electricity in Iraq based on Saddam and Samara dams. The estimated drop in Iraqi electricity generation capacity is put at 53% (Kolars, 1986).

Syrian, a closer country to the Euphrates and Tigris rivers have raised apprehensions over similar issues raised by the Iraqi authorities; that is, considerable reduction in water flow and pollution. It was stressed that prior to the completion of the Keban Dam (in the 1960s), the amount of water consumed by Turkey for irrigation was about only 3% of the Euphrates River.

However, at the completion of the Keban Dam, the span of land area irrigation using the Euphrates consumed about 10 billion m^3 of water annually. In addition, based on the impact of the Keban Dam, Syrian authorities estimated the reduction in the flow reaching Syrian border now at 40%. That is, Turkey alone will purportedly be consuming almost 50% of the Euphrates River flow. Even worse is that studies stressed that 50% of the remaining water flow which Syria and Iraq are left to grabble will have 11% of it polluted from irrigation water returned by Turkey to the Euphrates downstream (Swain, 2001).

The study of the initially proposed GAP strongly suggests that responsible authorities did not really give much thought to river pollution problems due to returned water from irrigation. There were apprehensions by Syria and Iraq over the gradual increase in the level of pollution of the Euphrates and Tigris rivers; particularly, increased salinity, pesticides and fertilizers from waters returned to the rivers after irrigation. The pollution of water is of course harmful to agricultural production and human well-being. In contrast to earlier claims by the Turkish authorities that such dam projects do not pose any serious threat to Syria and Iraq, there have been counter-counter claims the Ilisu dam has significant impacts on the environment. For example, Environmental Impact Assessment Report (EIAR) carried out reveals that Turkish dam projects would critically impact the neighbouring environment. Thorough studies stress that the building and operation of such projects would impact the hydrological profile of the Tigris River. There is also a strong tendency for such projects to alter the pattern of water flow; it is estimated that such large fluctuations in water flow pattern would reach the Syria border, some 64 km downstream (Yesilnacar & Uyanik, 2005).

The running of the Ataturk dam has also resulted into a boost in agricultural production within the region, based on irrigation services through the dam. Figure 2.10/2.17 shows the agricultural impact of the Ataturk dam on the Sanliurfa region in Turkey. It will be seen that the area of agricultural viability has significantly improved from 1990 to 1999. Where the Ataturk dam has many positive impacts on the surrounding region, which also result the increase of evapotranspiration from agriculture plantation influenced by irrigation water from Ataturk dam as well as evaporation in provenance of Ataturk lake water which will influence the hydrological cycle of the area by increasing amount of water molecules that progressively will increase precipitation.

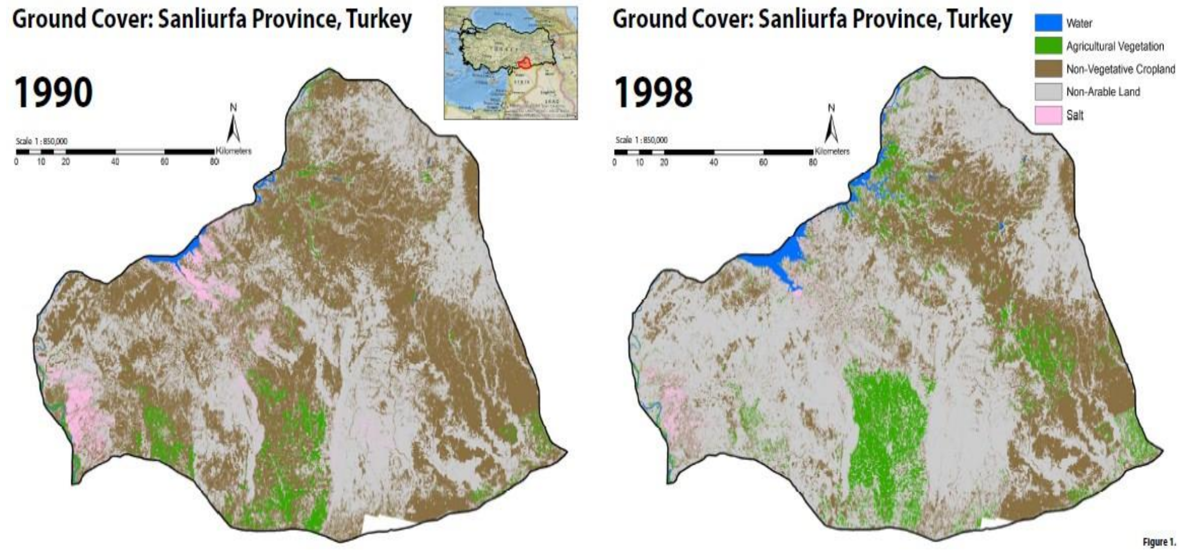

Figure 2.17: Ataturk agriculture impact on the Sanliurfa region, Turkey (Jooseph, 2013)

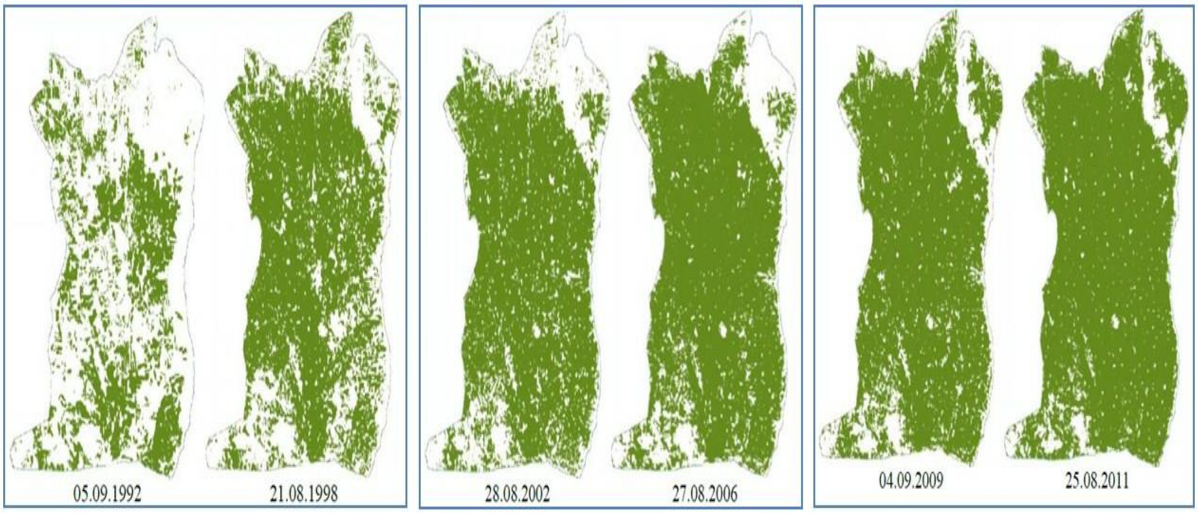

Figure 2.18: Spatiotemporal vegetation cover for the Haran Pain obtained Landsat images, ranging from 1992 to 2011

2.4 Summary

In this chapter, we present important insights into dam construction, siting requirements and construction after which emphasis is put on the subject of study, the Ataturk dam, Anatolia, Turkey. Lastly, we examine the pros and cons of such a project as the Ataturk dam on its environment, especially its impact on precipitation.

CHAPTER 3

DATA AND MODELLING TOOLS

3.1 Ataturk Dam Data

The climate data that are used in this work were collected from the Turkish State Meteorological Service (DMI). We obtained data on rainfall from three different stations: Adiyaman, Diyarbakir and Sanliurfa spanning the years 1936 to 2014 for winter, spring, summer and autumn seansons. Snapshots of such collected data for the different stations and seasons at some intervals are presented in Table 3.1, 3.2 & 3.3.

Table 3.1: Adiyaman station winter data for rainfall from 1963 to 2014

Parameter/Year	1963	1964	1965	1966	**….**	1992	1993	1994	**….**	2013	2014
Rainfall (mm)	192.4	87.4	148.9	184.8	**….**	137.8	103.1	142.2	**….**	179	95.8

Table 3.2: Diyarbakir station summer data for rainfall from 1963 to 2008

Parameter/Year	1936	1937	1938	1939	**….**	1992	1993	1994	**….**	2007	2008
Rainfall (mm)	9.1	4.9	4.6	6.4	**….**	13.3	2.4	1.0	**….**	6.6	2.1

Table 3.3: Sanliurfa station autumn data for rainfall from 1991 to 2012

Parameter/Year	1991	1992	1993	1994	**….**	2000	2001	2002	**….**	2011	2012
Rainfall (mm)	35.8	42.8	22.4	29.3	**…….**	14.4	34.1	31.5	**…….**	23.7	30.5

3.2 Regression modelling

In this section, we discuss sufficiently the modelling tools that are used within this for the analysis of data collected on the Ataturk dam. We have experimented with the popular modelling frameworks in this research which are multiple and polynomial regression models. We apply the aforementioned for the forecasting of Ataturk dam on important climate measures such as minimum and maximum temperature, precipitation and relative humidity.

Regression analysis can be employed for the exploring the relationship among variables. Generally, the aim is to observe how the change in one variable affects the other variables. In order to achieve this, data on the purported responsible for such changes are collected, and regression analysis used to explore quantitatively the influence of the causal variables on the variables that are affected. Scatter plots are plots of the causal variables against the affected variable. For example, Figure 3.1 shows the causal variable X plotted against affected (influenced) variable Y.

Regression analysis is a tool that allows one to approximate the relation between supposedly related variables. That is, one can use the variation in one or more variables to estimate the change in another variable; with the former being referred to as independent variable(s) and the latter referred to as dependent variable. Independent variables are also referred to as predictors. Note that independent variable(s) is (are) also referred to as regressors, explanatory or exogenous variables; while dependent variable(s) is (are) referred to as regressand, response or endogenous variable(s) (Harrell, 2015). There are several forms of regression analysis that are available for modelling different problems. Some of the commonly employed regression analyses include linear regression, logistic regression, polynomial regression, ridge regression, lasso regression, etc. The suitable type of regression analysis that should be employed depends on the nature of a particular problem, as one regression type may be considerably more appropriate than others.

3.2.1 Linear regression

Linear regression is perhaps the most popular regression form in regression analysis. Also, it is the basis for other regression forms. The independent variables may be in continuous or discrete, while the dependent is continuous. It assumes that the relationship between the independent variable(s) and dependent variable is a linear one. Note, that linear may falter seriously when employed in modelling data with non-linear relationship between the predictor(s) and dependent variable (Walker, 2003). When there is only one independent variable (predictor) for estimating the dependent variable, we refer to such as simple linear regression; while for more than one independent variable (predictor) for estimating the dependent variable, we refer to such as multiple linear regression. The major goal in regression analysis is to fit a line that best capture the influence of X on Y, or rather the statistical variation of X on Y.

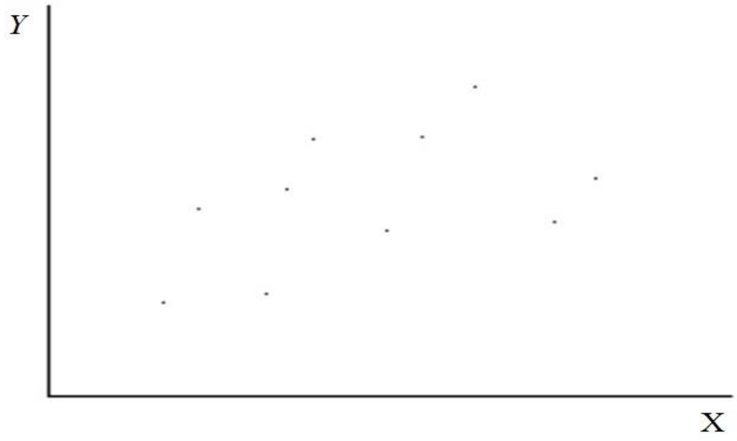

Figure 3.1: Sample of scatter plot

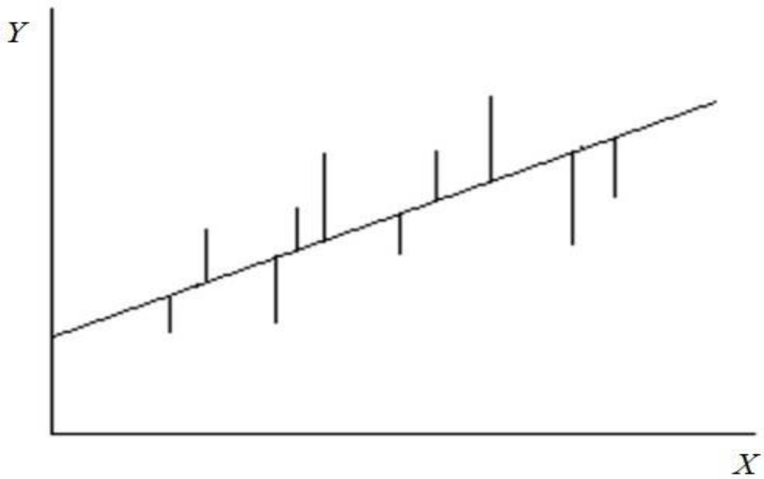

Figure 3.2: Finding line of best fit for data points

The problem is that there many lines, and the aim is to pick one of them that best capture the statistical nature of the data points as shown in Figure 3.1. For example, Figure 3.2x shows one of such lines of best fit. In order to obtain a line of best fit that largely capture such statistical nature of data points, an error term is often used for evaluating the different obtainable lines of best fit. The different obtainable lines of fit for data yields different values of error term; the idea is to select as the most suitable, the line of fit that yields the lowest value for the error term. Usually, the sum of squared errors (or least squared error) function is applied for performing such analysis. The least squared technique is used for fitting such lines to the scatter plot showing the data points for the independent (causal) variable and dependent (affected) variable. One important advantage of the sum of squared error function for obtaining the line of best fit is that is computationally inexpensive to obtain. More important is that differential calculus can be easily used to minimize the function to obtain the parameters of function which describes the equation for the line of best fit.

Generally a scatter plot can be plotted to systematically observe the nature of association between the independent variable(s) and dependent variable. In this work, we denote independent variable(s) with X and dependent variable with Y. Figure 3.3 shows a typical scatter plot (diagram). From the scatter plot, it is possible to observe the type of correlation that exist between the independent variable(x) and dependent variable (y), or if no correlation exists at all.

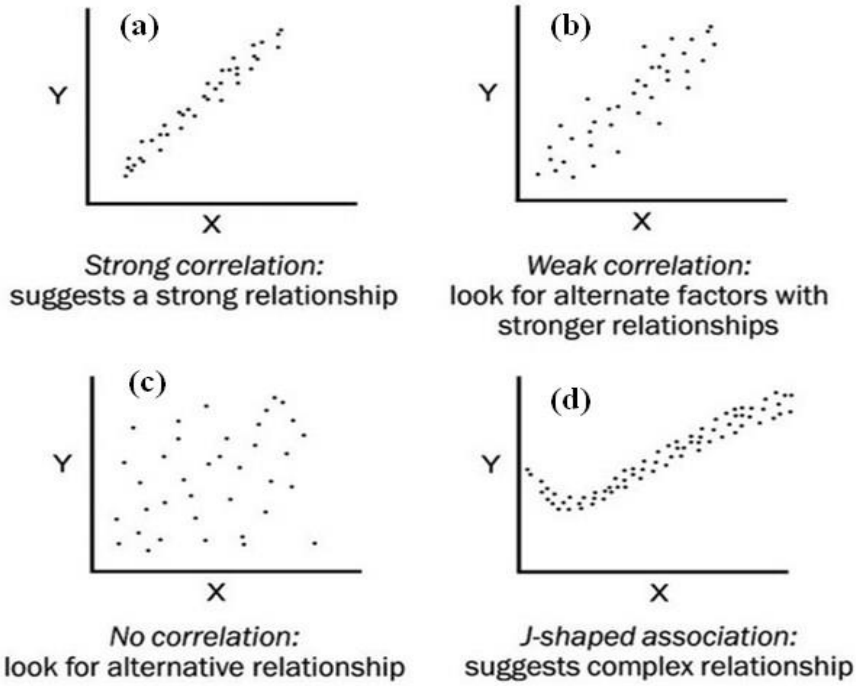

Figure 3.3: Scatter plot and correlation types (usaidassist.org/resources/scatter-diagrams, n.d.)

From Figure 3.3.a, it is seen that there is strongly linear and positive relationship between x and y; (3.3.b) shows a considerably linear and positive relationship between x and y; (3.3c) shows no relationship between x and y; (3.3.d) shows considerable but non-linear relationship between x and y. The linear regression is suitable in modelling data of the scatter plot nature shown in Figure 3.3 (a) & (b). Regression analysis is totalling out of scope for modelling data of the scatter plot nature shown in Figure 3.3c. For modelling data of the scatter plot nature shown in Figure 3.3d, other types of regression could be used. e.g. polynomial regression.

The idea is to fit a straight line that best models the linear relationship between the independent variable(s) and dependent variable; that is for data points in the scatter plot. The line is known as 'line of best fit' or regression line. For example, see Figure 3.4 for a typical regression line. The line of best fit (regression line) can be represented by Equation 3.1. Where, y is the dependent variable, x is the independent variable, c and m are the intercept and gradient (or regressor coefficient) of the line respectively, and e is the regression error which defines error contribution from sources other from the observed data.

$$y = c + mx + e \tag{3.1}$$

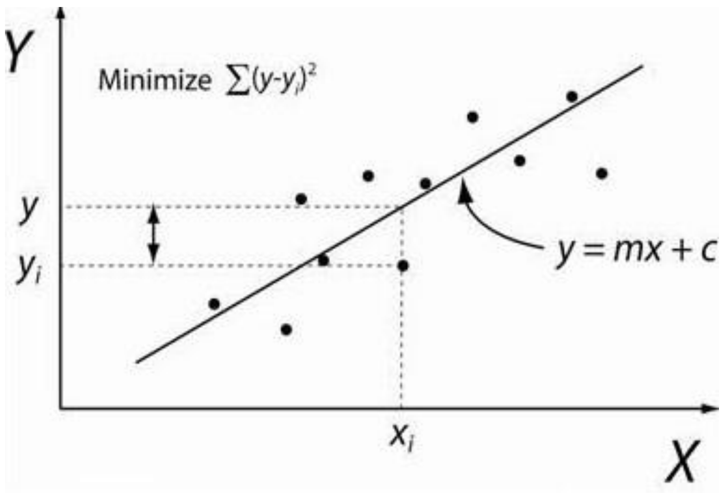

Figure 3.4: Typical regression line (www.atmos.washington.edu, n.d.)

Note that for many problems where we are largely certain that only the observed independent variable(s) are sufficient to estimate the dependent variable, the term 'e' can be ignored.

Some of the factors that can be used to determine the suitable type of regression form include

i. The number of independent variables.
ii. Shape of regression line.
iii. Type of dependent variable.

Furthermore, there exist some fundamental assumptions on regression analysis, without which such analysis may fail. These assumptions are briefly highlighted below (BR, 1988).

i. Presented samples are representative of the sample population.
ii. The error has a mean of zero based on the independent variables (predictors); the error is also a random variable.
iii. The predictors are linearly independent.
iv. The errors are not correlated
v. The error terms standard deviations are constant and do not depend on the independent variable(s).

In this work, we limit the scope of regression analysis to linear and polynomial forms. The following discussions give sufficient insight into linear and polynomial regression analysis.

In order to obtain the regression line, the regression line is oriented through data points such that it passes through as many data points as possible. Generally, the sum of square errors (SSE) approach is used to obtain a line that best fits data points. The SSE is given in Equation 3.2.

$$SSE = \sum_{n=1}^{N} (y - y_i)^2 \tag{3.2}$$

Where, y is a dependent data point on the regression line, y_i is an actual dependent data point and N is the total number of data points. The aim of linear regression analysis is to define the line of best fit by obtaining suitable values for c and m.

The regression coefficient (gradient of regression line), m, and intercept, c, can be obtained using Equations 3.3, 3.4 & 3.5.

$$m = r \frac{\sigma_Y}{\sigma_X} \tag{3.3}$$

Where, r is the correlation coefficient between variable Y and X; r can be obtained by using Equation 3.4.

$$r = \frac{n\sum xy - \left(\sum x\right)\left(\sum y\right)}{\sqrt{n\left(\sum x^2\right) - \left(\sum x\right)^2}\sqrt{n\left(\sum y^2\right) - \left(\sum y\right)^2}} \tag{3.4}$$

$$c = \bar{y} - m\bar{x} \tag{3.5}$$

Note that for multiple regression where there is more than one independent variable (regressors), the regression coefficients form a vector of the same dimensionality as the regressors or predictors. Also, critical points to be noted for determining the suitability of applying linear regression for modelling data are presented below.

i. There is linear relationship between regressors (independent variable(s)) and regressand (dependent variable).
ii. For multiple regression, there is no multicollinearity or autocorrelation.
iii. There are no outliers or extremely small outliers, as this extremely affects the developed model. i.e. obtained regression line.

3.2.2 Polynomial regression

Polynomial regression can be seen a regression tool for fitting non-linear data into a linear regression model based on the method of least squares. This is a type of linear regression that permits the prediction of the response variable, y, by decomposing the predictor variable, x, into a polynomial of nth order.

It is noteworthy that linear regression is only suitable for modelling data in which the regressors and regressand have a linear relationship. For complex or non-linear relationships between regressors and regressand, polynomial regression can be used for modelling data (Fu & Wang, 2004). The general form for polynomial regression is given Equation 3.14.

$$y = c_0 + c_1x + c_2x^2 + c_3x^3 + ... + c_nx^n + e \tag{3.14}$$

Where, c_0, c_1, c_2, c_3......c_n are the regression coefficients, n is shows the degree of the polynomial regression and e is an error term or model noise.

Polynomial regression can be quadratic, in which case $n = 2$, or strictly polynomial in which case $n>2$. The complexity of the relationship between the independent variable and dependent variable would determine the degree of the polynomial regression. That is, for moderately complex relationship, n can value low values; while for extremely complex relationships, n can be higher. However, care should be taken when determining the degree of polynomial for regression analysis such that the developed model becomes an overly tuned to every idiosyncrasies found only in the training data; a situation referred to as over-fitting. On the other hand, selecting a polynomial degree with inadequate capacity to model the important associations in the training data yield models which perform poorly even on the training data; a situation referred to as under-fitting. Analytical approaches can be used in obtaining regression coefficients for polynomial regression (Isaac et al., 2012). The developed model (regression curve) can be tested on new (unseen) data to ascertain its generalization capacity.

The order of polynomial regression is successively increased to observe if the coefficient of determination, r^2, increases significantly. That is determining the suitable order of polynomial that best models a given data is through heuristic. Figure 3.7 shows polynomial regression of different orders. The linear regression is simply a straight line. The quadratic polynomial regression; that is, of second order, gives a parabola. The cubic polynomial regression; that is, of third order, gives a s-shaped curve. i.e. see Figure 3.7. A thorough study of the curves shows that has the order of regression polynomial increases, the flexibility of the model increases; that is, its degree of freedom to capture more variations in data. For data with a single curvilinear line, the quadratic polynomial regression is appropriate. For data curves with two bends, the cubic polynomial regression is appropriate. For data curves more curves, much higher order polynomial regression is appropriate to capture the highly varying nature of data. However, using a high order polynomial regression may largely capture the highly varying nature of data, and in fact also capture idiosyncrasies found in the training data; that is, a form of overly perfect-fitting of the model to the training data that comes with generalization loss of the model. Actually, with high order polynomial regression, it is not uncommon that the regression begins to model even noise which may be present in the training data. At test time, such modelled noise may impact the model such that it yields very poor results on unseen data (Gilmour & Trinca, 2000). Hence, the order of the polynomial should be taken into account such that over-fitting to training data is discouraged.

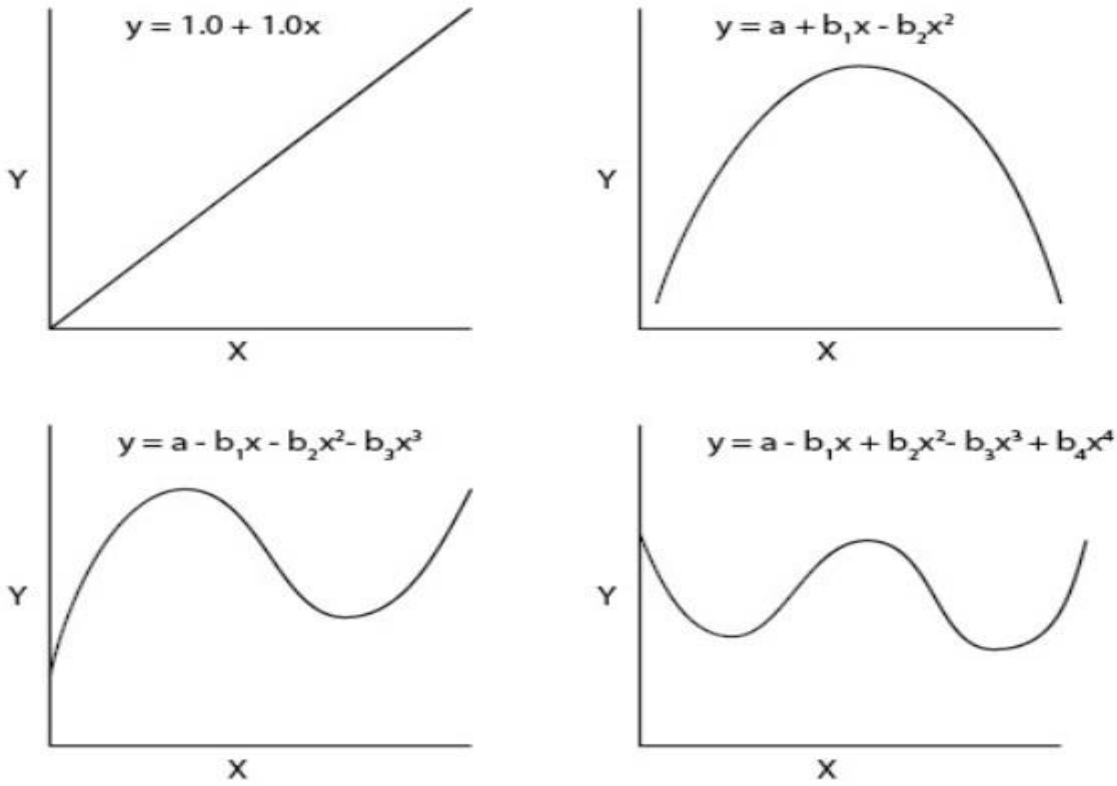

Figure 3.5: Polynomial regression with different orders. Top left: order of 1. Top right: order of 2. Bottom left: order of 3. Bottom right: order of 4

Significance test

The significance is necessary to be performed after successive increase in the order of regression polynomial. This permits the observation of the amount of variance explain by successive order of polynomial regression. At a stage, where is no or significant increase in amount of variance explained by the next higher order polynomial, then the increase in order of regression polynomial is stopped. If the amount of variance explained increases, then the value for the coefficient of determination, r^2, increases considerably (Sinha, 2013).

Generally, one starts by testing to examine if data are linear; if that is true, then one stops as a linear regression model is appropriate enough to capture the variation in data. In case, the coefficient of determination is small for linear regression, then the quadratic regression is tested; its coefficient of determination is compared with that of the linear regression. This process is repeated in this manner until a high coefficient of determination is obtained. This progressive regression scheme can be expressed as shown in Equations 3.15 & 3.16.

$$H_0: \; r_n^2 = r_{n+1}^2 \tag{3.15}$$

$$H_1: \; r_n^2 < r_{n+1}^2 \tag{3.16}$$

Where, n represents the order of the polynomial regression; r^2 is coefficient of determination for the polynomial regression model; H_0 is the null hypothesis and H_1 represents the accepted hypothesis if the null hypothesis is false.

3.3 Summary

In this chapter, we present climatic data collected on the Ataturk dam. Such data range from precipitation, temperature, relative humidity, etc. The hope is to use such relations to forecast the future impact of Ataturk dam on it is environment, especially climate change. Furthermore, we introduce sufficiently some analytical tools for modelling the progressive nature of climatic change as a result of running Ataturk dam. We give discussion on data modelling tools such as regression analysis, backpropagation neural network and radial basis function neural network. Also, we share motivations, pros and cons for such tools as employed within this work.

CHAPTER 4

DATA MODELLING, RESULTS ANALYSIS AND DISCUSSION

4.1 Regression Modelling

Here, we present the modelling of rainfall data over time around Ataturk dam region. Firstly, we consider the linear regression settings discussed in chapter 3, section 3.3.1. Hence, the regression models have one independent variable: present year rainfall; and dependent variables: next year rainfall. Climate data from year 1963-2000 are used for building the regression models, while climate data from year 2001-2014 are used for validating the performance of the developed models. Particularly, we also employ two different averaging strategies for modelling rainfall based on the weather readings from the three different weather stations. The direct mean strategy as showed in Equation 4.1 as P_m, while the Thiessen polygon method (TPM) for mean is showed in Equation 4.2; P_a, P_d, P_s are the precipitation readings for Adiyaman, Diyarbakir and Sanliurfa weather stations, respectively.

$$P_m = \frac{1}{3}(P_a + P_d + P_s) \tag{4.1}$$

$$P_{TPM} = \frac{P_a A_a + P_d A_d + P_s A_s}{A_a + A_d + A_s} \tag{4.2}$$

Where, A_a, A_d and A_s are the areas of Adiyaman, Diyarbakir and Sanliurfa regions, respectively. Note that $A_a = 7871\ km^2$, $A_d = 17280\ km^2$ and $A_s = 18584\ km^2$.

4.1.1 Linear regression (LR)

The aim of linear regression is to obtain a line of best fit relating the independent variable and dependent variable. Using the aforementioned independent variable, we develop separate models based on available data from three different weather stations to obtain the line of best fit for the dependent variable. i.e. next year rainfall. We analyse the rainfall data for the three stations over different seasons; that is, winter, spring, summer and autumn.

(a) Winter

Leveraging on the linear regression equations provided in chapter 3, section 3.3.1; we obtain the linear regression model for rainfall expressed by Equation 4.1.

$$y_{(n+1)} = mx_{(n)} + c \qquad (4.3)$$

Where, $y_{(n+1)}$ is next year rainfall value for the winter season; $x_{(n)}$ to represent the independent variable present year rainfall for the winter season; m, is the line gradient for the independent variable and c_w is the intercept. We present for the sole purpose of intuition some systems of equations that can be related with based on some observed independent and dependent variables for the modelling of rainfall for the 3 different stations: Adiyaman, Diyarbakir and Sanliurfa, respectively. Equations 4.2, 4.3 & 4.4 are for the Adiyaman station data variables denoted with the subscript 'a' for the years 1964, 1965 & 2000. Equations 4.5, 4.6 & 4.7 are for the Diyarbakir station data variables denoted with subscript 'd' for the years 1937, 1938 & 2000. Equations 4.8, 4.9 & 4.10 are for the Sanliurfa station data variables denoted with subscript 's' for the years 1992, 1993 & 2000.

$$y_{a(1964)} \rightarrow 192.4m_a + c_a = 87.4 \qquad (4.4)$$

$$y_{a(1965)} \rightarrow 87.4m_a + c_a = 148.9 \qquad (4.5)$$

..

..

$$y_{a(2000)} \rightarrow 119.4m_a + c_a = 129.4 \qquad (4.6)$$

$$y_{d(1937)} \rightarrow 83.3m_d + c_d = 46.7 \qquad (4.7)$$

$$y_{d(1938)} \rightarrow 46.7m_d + c_d = 95.2 \qquad (4.8)$$

..

..

$$y_{d(2000)} \rightarrow 41.1m_d + c_d = 53.5 \qquad (4.9)$$

$$y_{s(1992)} \rightarrow 41.9m_s + c_s = 14.9 \qquad (4.10)$$

$$y_{s(1993)} \rightarrow 14.9m_s + c_s = 30.3 \qquad (4.11)$$

..

..

$$y_{s(2000)} \rightarrow 49.8m_s + c_s = 22.8 \quad (4.12)$$

Employing the method of least squares and linear regression, the model parameters m_a, m_d, m_s, c_a, c_d and c_s are obtained for estimating, $\overline{y_{a(n+1)}}$, $\overline{y_{d(n+1)}}$ and $\overline{y_{s(n+1)}}$ as shown in Equations 4.13, 4.14 & 4.15. Equation 4.16 & 4.17 show the models based on the average of the three weather stations using direct mean (m) and Thiessen polygon method (TPM); where, x_m is the present year direct mean rainfall and y_m is next year direct mean rainfall; x_{TPM} is the present year TPM mean rainfall and y_{TPM} is next year TPM mean rainfall.

$$\overline{y_{a(n+1)}} = -0.5839x_{a(n)} + 199.6 \quad (4.13)$$

$$\overline{y_{d(n+1)}} = -0.5802x_{d(n)} + 98.2 \quad (4.14)$$

$$\overline{y_{s(n+1)}} = -0.3061x_{s(n)} + 33.5 \quad (4.15)$$

$$\overline{y_{m(n+1)}} = -0.4728x_{m(n)} + 41.9 \quad (4.16)$$

$$\overline{y_{TPM(n+1)}} = -0.4162x_{TPM(n)} + 65.7 \quad (4.17)$$

(b) Spring

Linear regression model for estimating rainfall for spring seasons is developed using Equations presented in chapter 3, section 3.3.1, where $y_{a(n+1)}$, $y_{d(n+1)}$ and $y_{s(n+1)}$ are the actual next year rainfall values for the spring season for the stations Adiyaman, Diyarbakir and Sanliurfa, respectively; $x_{(n)}$ is the present year rainfall for the spring season for the stations Adiyaman, Diyarbakir and Sanliurfa, respectively; m is respective line gradients for the independent variables, and c is the intercept.

Equations 4.18, 4.19 & 4.20 are for the Adiyaman station data variables denoted with the subscript ‘a’ for spring seasons for the years 1964, 1965 & 2000. Equations 4.21, 4.22 & 4.23 are for the Diyarbakir station data variables denoted with subscript ‘d’ for spring seasons for the years 1937, 1938 & 2000. Equations 4.24, 4.25 & 4.26 are for the Sanliurfa station data variables denoted with subscript ‘s’ for spring seasons for the years 1992, 1993 & 2000.

$$y_{a(1964)} \rightarrow 124.9m_a + c_a = 81.9 \quad (4.18)$$

$$y_{a(1965)} \rightarrow 81.9m_a + c_a = 42.3 \tag{4.19}$$

..

..

$$y_{a(2000)} \rightarrow 48.8m_a + c_a = 29.4 \tag{4.20}$$

$$y_{d(1937)} \rightarrow 75.3m_d + c_d = 44.3 \tag{4.21}$$

$$y_{d(1938)} \rightarrow 44.3m_d + c_d = 25.7 \tag{4.22}$$

..

..

$$y_{d(2000)} \rightarrow 50.2m_d + c_d = 23.3 \tag{4.23}$$

$$y_{s(1992)} \rightarrow 48.8m_s + c_s = 26.7 \tag{4.24}$$

$$y_{s(1993)} \rightarrow 26.7m_s + c_s = 37.8 \tag{4.25}$$

..

..

$$y_{s(2000)} \rightarrow 32.3m_s + c_s = 66.8 \tag{4.26}$$

Employing the method of least squares and linear regression, the model parameters m_a, m_d, m_s, c_a, c_d and c_s are obtained for estimating, $\overline{y_{a(n+1)}}$, $\overline{y_{d(n+1)}}$ and $\overline{y_{s(n+1)}}$ as shown in Equations 4.27, 4.28 & 4.29. Equation 4.30 & 4.31 show the models based on the average of the three weather stations using direct mean (m) and Thiessen polygon method (TPM); where, x_m is the present year direct mean rainfall and y_m is next year direct mean rainfall; x_{TPM} is the present year TPM mean rainfall and y_{TPM} is next year TPM mean rainfall.

$$\overline{y_{a(n+1)}} = -0.7011x_{a(n)} - 8.5372 \tag{4.27}$$

$$\overline{y_{d(n+1)}} = 0.6701x_{d(n)} - 6.8304 \tag{4.28}$$

$$\overline{y_{s(n+1)}} = -0.9401x_{s(n)} + 77.5 \tag{4.29}$$

$$\overline{y_{m(n+1)}} = -0.7285x_{m(n)} + 24.8 \tag{4.29}$$

$$\overline{y_{TPM(n+1)}} = -0.6402x_{TPM(n)} + 32.1 \tag{4.31}$$

(c) Summer

Linear regression model for estimating rainfall for summer seasons along years for the different weather stations are is developed using Equations 4.32 – 4.40; where $y_{a(n+1)}$, $y_{d(n+1)}$ and $y_{s(n+1)}$ are the actual next year rainfall values for the summer season for the stations Adiyaman, Diyarbakir and Sanliurfa, respectively; m is respective line gradients for the independent variables, and c is the intercept.

$$y_{a(1964)} \rightarrow 0.6m_a + c_a = 4.4 \tag{4.32}$$

$$y_{a(1965)} \rightarrow 4.4m_a + c_a = 0.0 \tag{4.33}$$

..

..

$$y_{a(2000)} \rightarrow 1.3m_a + c_a = 0.8 \tag{4.34}$$

$$y_{d(1937)} \rightarrow 9.1m_d + c_d = 4.9 \tag{4.35}$$

$$y_{d(1938)} \rightarrow 4.9m_d + c_d = 4.6 \tag{4.36}$$

..

..

$$y_{d(2000)} \rightarrow 1.0m_d + c_d = 0.3 \tag{4.37}$$

$$y_{s(1992)} \rightarrow 28.6m_s + c_s = 34.0 \tag{4.38}$$

$$y_{s(1993)} \rightarrow 34.0m_s + c_s = 11.6 \tag{4.39}$$

..

..

$$y_{s(2000)} \rightarrow 15.1m_s + c_s = 12.9 \tag{4.40}$$

Employing the method of least squares and linear regression, the model parameters m_a, m_d, m_s, c_a, c_d and c_s are obtained for estimating, $\overline{y_{a(n+1)}}$, $\overline{y_{d(n+1)}}$ and $\overline{y_{s(n+1)}}$ as shown in Equations 4.41, 4.42 & 4.43. Equation 4.44 & 4.45 show the models based on the average of the three weather stations using direct mean (m) and Thiessen polygon method (TPM); where, x_m is the present year direct mean rainfall and y_m is next year direct mean rainfall; x_{TPM} is the present year TPM mean rainfall and y_{TPM} is next year TPM mean rainfall.

$$\overline{y_{a(n+1)}} = -0.8851x_{a(n)} + 3.6 \quad (4.41)$$

$$\overline{y_{d(n+1)}} = 0.5615x_{d(n)} + 0.5 \quad (4.42)$$

$$\overline{y_{s(n+1)}} = 0.2450x_{s(n)} + 13.2 \quad (4.43)$$

$$\overline{y_{m(n+1)}} = 0.3165x_{m(n)} + 16.8 \quad (4.44)$$

$$\overline{y_{TPM(n+1)}} = 0.4711x_{TPM(n)} + 10.3 \quad (4.45)$$

(d) Autumn

Linear regression model for estimating rainfall for autumn seasons along years for the different weather stations are is developed using Equations 4.46– 4.60; where $y_{a(n+1)}$, $y_{d(n+1)}$ and $y_{s(n+1)}$ are the actual next year rainfall values for the summer season for the stations Adiyaman, Diyarbakir and Sanliurfa, respectively; m is respective line gradients for the independent variables, and c is the intercept.

$$y_{a(1964)} \rightarrow 31.1m_a + c_a = 40.4 \quad (4.46)$$

$$y_{a(1965)} \rightarrow 40.4m_a + c_a = 50.5 \quad (4.47)$$

..

..

$$y_{a(2000)} \rightarrow 8.3m_a + c_a = 29.9 \quad (4.48)$$

$$y_{d(1937)} \rightarrow 50.3m_d + c_d = 55.5 \quad (4.49)$$

$$y_{d(1938)} \rightarrow 55.5m_d + c_d = 38.5 \quad (4.50)$$

..

..

$$y_{d(2000)} \rightarrow 5.0m_d + c_d = 23.3 \quad (4.51)$$

$$y_{s(1992)} \rightarrow 35.8m_s + c_s = 42.8 \quad (4.52)$$

$$y_{s(1993)} \rightarrow 42.8m_s + c_s = 22.4 \quad (4.53)$$

..

..

$$y_{s(2000)} \rightarrow 18.3m_s + c_s = 14.4 \tag{4.54}$$

Employing the method of least squares and linear regression, the model parameters m_a, m_d, m_s, c_a, c_d and c_s are obtained for estimating, $\overline{y_{a(n+1)}}$, $\overline{y_{d(n+1)}}$ and $\overline{y_{s(n+1)}}$ shown in Equation 4.47, 4.48 & 4.49. Equation 4.58 & 4.59 show the models based on the average of the three weather stations using direct mean (m) and Thiessen polygon method (TPM); where, x_m is the present year direct mean rainfall and y_m is next year direct mean rainfall; x_{TPM} is the present year TPM mean rainfall and y_{TPM} is next year TPM mean rainfall.

$$\overline{y_{a(n+1)}} = 0.6077x_{a(n)} + 24.1028 \tag{4.55}$$

$$\overline{y_{d(n+1)}} = 0.4618x_{d(n)} + 22.0441 \tag{4.56}$$

Table 4.1: Linear regression model mean squared error (MES) for the different stations

Parameter/season	Winter	Spring	Summer	Autumn
Adiyaman	0.1242	0.1147	0.1082	0.1013
Diyarbakir	0.0931	0.0748	0.0572	0.065
Sanliurfa	0.1361	0.1325	0.1145	0.1128
Mean (direct: m)	0.0118	0.1063	0.0917	0.0879
Mean (Thiessen polygon method: TPM)	0.0106	0.0926	0.0741	0.0765

Table 4.2: Linear regression model coefficient of determination (r^2) for different stations

Parameter/season	Winter	Spring	Summer	Autumn
Adiyaman	0.6215	0.6475	0.6524	0.6615
Diyarbakir	0.6846	0.7285	0.7931	0.7537
Sanliurfa	0.5987	0.6197	0.6259	0.6308
Mean (direct: m)	0.6373	0.6549	0.6972	0.6895
Mean (Thiessen polygon method: TPM)	0.6585	0.6971	0.7484	0.7358

$$\overline{y_{s(n+1)}} = 0.5758x_{s(n)} + 7.9342 \tag{4.57}$$

$$\overline{y_{m(n+1)}} = 0.6269 x_{m(n)} + 15.3174 \tag{4.58}$$

$$\overline{y_{TPM(n+1)}} = 0.5382 x_{TPM(n)} + 17.6 \tag{4.59}$$

Table 4.1 shows the obtained mean squared error (MSE) of the linear regression models for the different weather stations for different seasons, and the average of data for the three weather stations. It will be seen that the least average MSE is obtained for the Diyarbakir weather station, which is followed the average data. Adiyaman weather station follows the average of weather stations on low MSEs; while, Sanliurfa weather station has the highest average MSE on all seasons. Table 4.2 show the coefficient of determination for the models, a parameter that estimates how much of variance between the independent and dependent variable explained by the models. Again, it will be seen that Diyarbakir weather station has the highest average coefficient of determination on all seasons, followed by the average of weather stations and then Adiyaman weather station; Sanliurfa weather station has the lowest average coefficient of determination.

4.1.2 Polynomial regression (PR)

Here, polynomial regression of the second order is experimented with is presented for modelling the same climate data for the linear regression model. The aim is that with more degree of freedom, the statistical features in the climate data can be better captured.

Leveraging on the quadratic regression equations provided in chapter 3; we obtain the quadratic regression model for precipitation expressed by Equation 4.60.

$$y_{(n+1)} = m_2 x_{(n)}^2 + m_1 x_{(n)} + c \tag{4.60}$$

Where, $y_{(n+1)}$ is next year rainfall; $x_{(n)}$ represents the independent variable present year rainfall; m_1, m_2 & c are coefficients of regression.

We present for the sole purpose of intuition some systems of equations that can be related with based on some observed independent and dependent variables for the modelling of rainfall along the winter, spring, summer and autumn seasons for the different weather stations. Particularly, we use the present season rainfall to predict next year rainfall.

(a) Winter

Where, $y_{(n+1)}$ is next year rainfall value for the winter season; $x_{(n)}$ to represent the independent variable present year rainfall for the winter season. We present some systems of equations that can be related with based on some observed independent and dependent variables for the modelling of rainfall for the 3 different stations: Adiyaman, Diyarbakir and Sanliurfa, respectively. Equations 4.61, 4.62 & 4.63 are for the Adiyaman station data variables denoted with the subscript 'a' for the years 1964, 1965 & 2000. Equations 4.64, 4.65 & 4.66 are for the Diyarbakir station data variables denoted with subscript 'd' for the years 1937, 1938 & 2000. Equations 4.67, 4.68 & 4.69 are for the Sanliurfa station data variables denoted with subscript 's' for the years 1992, 1993 & 2000.

$$y_{a(1964)} \rightarrow 37017.7m_{a1} + 192.4m_{a2} + c_a = 87.4 \quad (4.61)$$

$$y_{a(1965)} \rightarrow 7638.8m_{a2} + 87.4m_{a1} + c_a = 148.9 \quad (4.62)$$

..

..

$$y_{a(2000)} \rightarrow 14256.4m_{a2} + 119.4m_{a1} + c_a = 129.4 \quad (4.63)$$

$$y_{d(1937)} \rightarrow 6938.9m_{d2} + 83.3m_{d1} + c_d = 46.7 \quad (4.64)$$

$$y_{d(1938)} \rightarrow 2180.9m_{d2} + 46.7m_{d1} + c_d = 95.2 \quad (4.65)$$

..

..

$$y_{d(2000)} \rightarrow 1689.2m_{d2} + 41.1m_{d1} + c_d = 53.5 \quad (4.66)$$

$$y_{s(1992)} \rightarrow 1755.6m_{s2} + 41.9m_{s1} + c_s = 14.9 \quad (4.67)$$

$$y_{s(1993)} \rightarrow 222.0m_{s2} + 14.9m_{s1} + c_s = 30.3 \quad (4.68)$$

..

..

$$y_{s(2000)} \rightarrow 2480.0m_{s2} + 49.8m_{s1} + c_s = 22.8 \quad (4.69)$$

Employing the method of least squares and linear regression, the model parameters m_a, m_d, m_s, c_a, c_d and c_s are obtained for estimating, $\overline{y_{a(n+1)}}$, $\overline{y_{d(n+1)}}$ and $\overline{y_{s(n+1)}}$ as shown in Equations 4.70, 4.71 & 4.72. Equation 4.73 & 4.74 show the models based on the average of the three weather stations using direct mean (m) and Thiessen polygon method (TPM); where, x_m is the present year direct mean rainfall and y_m is next year direct mean rainfall; x_{TPM} is the present year TPM mean rainfall and y_{TPM} is next year TPM mean rainfall.

$$\overline{y_{a(n+1)}} = 0.0003x_{a(n)}^2 - 0.6764x_{a(n)} + 205.5 \quad (4.70)$$

$$\overline{y_{d(n+1)}} = -0.2079x_{d(n)}^2 + 25.6986x_{d(n)} - 651.6 \quad (4.71)$$

$$\overline{y_{s(n+1)}} = 0.0450x_{s(n)}^2 - 3.1264x_{s(n)} + 66.9 \quad (4.72)$$

$$\overline{y_{m(n+1)}} = -0.5382x_{m(n)}^2 + 28.0196x_{m(n)} - 642.5 \quad (4.73)$$

$$\overline{y_{TPM(n+1)}} = -0.1737x_{TPM(n)}^2 + 23.6281x_{TPM(n)} - 626.3 \quad (4.74)$$

(b) Spring

Quadratic regression model for estimating rainfall for spring seasons is developed using Equations presented in chapter 3, section 3.3.1, where $y_{a(n+1)}$, $y_{d(n+1)}$ and $y_{s(n+1)}$ are the actual next year rainfall values for the spring season for the stations Adiyaman, Diyarbakir and Sanliurfa, respectively; $x_{(n)}$ is the present year rainfall for the spring season for the stations Adiyaman, Diyarbakir and Sanliurfa, respectively.

Equations 4.75, 4.76 & 4.77 for the Adiyaman station data variables denoted with the subscript ‘a’ for spring seasons for the years 1964, 1965 & 2000. Equations 4.78, 4.79 & 4.80 are for the Diyarbakir station data variables denoted with subscript ‘d’ for spring seasons for the years 1937, 1938 & 2000. Equations 4.81, 4.82 & 4.83 are for the Sanliurfa station data variables denoted with subscript ‘s’ for spring seasons for the years 1992, 1993 & 2000.

$$y_{a(1964)} \rightarrow 15600.0m_{a2} + 124.9m_{a1} + c_a = 81.9 \quad (4.75)$$

$$y_{a(1965)} \rightarrow 6707.6m_{a2} + 81.9m_{a1} + c_a = 42.3 \quad (4.76)$$

$$\vdots$$

$$y_{a(2000)} \rightarrow 2381.4m_{a2} + 48.8m_{a1} + c_a = 29.4 \quad (4.77)$$

$$y_{d(1937)} \rightarrow 5670.1m_{d2} + 75.3m_{d1} + c_d = 44.3 \quad (4.78)$$

$$y_{d(1938)} \rightarrow 1962.5m_{d2} + 44.3m_{d1} + c_d = 25.7 \quad (4.79)$$

..

..

$$y_{d(2000)} \rightarrow 2520.0m_{d2} + 50.2m_{d1} + c_d = 23.3 \tag{4.80}$$

$$y_{s(1992)} \rightarrow 2381.4m_{s2} + 48.8m_{s1} + c_s = 26.7 \tag{4.81}$$

$$y_{s(1993)} \rightarrow 712.9m_{s2} + 26.7m_{s1} + c_s = 37.8 \tag{4.82}$$

..

..

$$y_{s(2000)} \rightarrow 1043.3m_{s2} + 32.3m_{s1} + c_s = 66.8 \tag{4.83}$$

Employing the method of least squares and linear regression, the model parameters m_a, m_d, m_s, c_a, c_d and c_s are obtained for estimating, $\overline{y_{a(n+1)}}$, $\overline{y_{d(n+1)}}$ and $\overline{y_{s(n+1)}}$ as shown in Equations 4.84, 4.85 & 4.86.

$$\overline{y_{a(n+1)}} = 0.0070x_{a(n)}^2 - 0.5224x_{a(n)} + 38.3 \tag{4.84}$$

$$\overline{y_{d(n+1)}} = 0.0401x_{d(n)}^2 - 4.1956x_{d(n)} + 132.9 \tag{4.85}$$

$$\overline{y_{s(n+1)}} = -0.3443x_{s(n)}^2 + 25.4946x_{s(n)} - 397.4 \tag{4.86}$$

$$\overline{y_{m(n+1)}} = -0.0267x_{m(n)}^2 + 8.1037x_{m(n)} - 265.2 \tag{4.87}$$

Equation 4.87 & 4.88 show the models based on the average of the three weather stations using direct mean (m) and Thiessen polygon method (TPM); where, x_m is the present year direct mean rainfall and y_m is next year direct mean rainfall; x_{TPM} is the present year TPM mean rainfall and y_{TPM} is next year TPM mean rainfall.

(c) Summer

Quadratic regression model for estimating rainfall for summer seasons along years for the different weather stations are is developed using Equations 4.89 – 4.97; where $y_{a(n+1)}$, $y_{d(n+1)}$ and $y_{s(n+1)}$ are the actual next year rainfall values for the summer season for the stations Adiyaman, Diyarbakir and Sanliurfa, respectively.

$$y_{a(1964)} \rightarrow 0.30m_{a2} + 0.55m_{a1} + c_a = 4.4 \tag{4.89}$$

$$y_{a(1965)} \rightarrow 19.4m_{a2} + 4.4m_{a1} + c_a = 0.0 \tag{4.90}$$

..

..

$$y_{a(2000)} \rightarrow 1.7m_{a2} + 1.3m_{a1} + c_a = 0.8 \tag{4.91}$$

$$y_{d(1937)} \rightarrow 82.81m_{d2} + 9.1m_{d1} + c_d = 4.85 \tag{4.92}$$

$$y_{d(1938)} \rightarrow 24.0m_{d2} + 4.9m_{d1} + c_d = 4.55 \tag{4.93}$$

..

..

$$y_{d(2000)} \rightarrow 1.0m_{d2} + 1.0m_{d1} + c_d = 0.3 \tag{4.94}$$

$$y_{s(1992)} \rightarrow 817.9m_{s2} + 28.6m_{s1} + c_s = 34.0 \tag{4.95}$$

$$y_{s(1993)} \rightarrow 1156m_{s2} + 34.0m_{s1} + c_s = 11.6 \tag{4.96}$$

..

..

$$y_{s(2000)} \rightarrow 228.0m_{s2} + 15.1m_{s1} + c_s = 12.9 \tag{4.97}$$

Employing the method of least squares and linear regression, the model parameters m_a, m_d, m_s, c_a, c_d and c_s are obtained for estimating, $\overline{y_{a(n+1)}}$, $\overline{y_{d(n+1)}}$ and $\overline{y_{s(n+1)}}$ as shown in Equations 4.98, 4.99 & 4.100. Equation 4.101 & 4.102 show the models based on the average of the three weather stations using direct mean (m) and Thiessen polygon method (TPM); where, x_m is the present year direct mean rainfall and y_m is next year direct mean rainfall; x_{TPM} is the present year TPM mean rainfall and y_{TPM} is next year TPM mean rainfall.

$$\overline{y_{a(n+1)}} = 1.1819x_{a(n)}^2 - 7.0062x_{a(n)} + 7.9 \tag{4.98}$$

$$\overline{y_{d(n+1)}} = -0.1256x_{d(n)}^2 + 1.8307x_{d(n)} - 1.4 \tag{4.99}$$

$$\overline{y_{s(n+1)}} = -0.3019x_{s(n)}^2 + 14.7566x_{s(n)} - 141.1 \tag{4.100}$$

$$\overline{y_{m(n+1)}} = -0.1573x_{m(n)}^2 + 8.2731x_{m(n)} - 139.5 \tag{4.101}$$

$$\overline{y_{TPM(n+1)}} = -0.1405 x_{TPM(n)}^2 + 2.7649 x_{TPM(n)} - 1.1 \quad (4.102)$$

(d) Autumn

Quadratic regression model for estimating rainfall for autumn seasons along years for the different weather stations are is developed using Equations 4.103– 4.111; where $y_{a(n+1)}$, $y_{d(n+1)}$ and $y_{s(n+1)}$ are the actual next year rainfall values for the summer season for the stations Adiyaman, Diyarbakir and Sanliurfa, respectively.

$$y_{a(1964)} \rightarrow 967.2 m_{a2} + 31.1 m_{a1} + c_a = 40.4 \quad (4.103)$$

$$y_{a(1965)} \rightarrow 1632.2 m_{a2} + 40.4 m_{a1} + c_a = 50.5 \quad (4.104)$$

..

..

$$y_{a(2000)} \rightarrow 68.9 m_{a2} + 8.3 m_{a1} + c_a = 29.9 \quad (4.105)$$

$$y_{d(1937)} \rightarrow 2530.1 m_{d2} + 50.3 m_{d1} + c_d = 55.45 \quad (4.106)$$

$$y_{d(1938)} \rightarrow 3080.3 m_{d2} + 55.5 m_{d1} + c_d = 38.5 \quad (4.107)$$

..

..

$$y_{d(2000)} \rightarrow 25.0 m_{d2} + 5.0 m_{d1} + c_d = 23.3 \quad (4.108)$$

$$y_{s(1992)} \rightarrow 1281.6 m_{s2} + 35.8 m_{s1} + c_s = 42.8 \quad (4.109)$$

$$y_{s(1993)} \rightarrow 1831.8 m_{s2} + 42.8 m_{s1} + c_s = 22.4 \quad (4.110)$$

..

..

$$y_{s(2000)} \rightarrow 334.9 m_{s2} + 18.3 m_{s1} + c_s = 14.4 \quad (4.111)$$

Employing the method of least squares and linear regression, the model parameters m_a, m_d, m_s, c_a, c_d and c_s are obtained for estimating, $\overline{y_{a(n+1)}}$, $\overline{y_{d(n+1)}}$ and $\overline{y_{s(n+1)}}$ shown in Equation 4.112, 4.113 & 4.114. Equation 4.115 & 4.116 show the models based on the average of the three weather stations using direct mean (m) and Thiessen polygon method (TPM); where, x_m is the present year direct mean rainfall and y_m is next year direct mean rainfall; x_{TPM} is the present year TPM mean rainfall and y_{TPM} is next year TPM mean rainfall.

$$\overline{y_{a(n+1)}} = 0.0195x_{a(n)}^2 - 0.3070x_{a(n)} + 31.1 \tag{4.112}$$

$$\overline{y_{d(n+1)}} = -0.0699x_{d(n)}^2 + 4.5741x_{d(n)} + 2.2 \tag{4.113}$$

$$\overline{y_{s(n+1)}} = -0.1852x_{s(n)}^2 + 11.6399x_{s(n)} - 136.6 \tag{4.114}$$

$$\overline{y_{m(n+1)}} = -0.1407x_{m(n)}^2 + 10.5294x_{m(n)} - 128.5 \tag{4.115}$$

$$\overline{y_{TPM(n+1)}} = -0.1614x_{TPM(n)}^2 + 13.2058x_{TPM(n)} - 126.2 \tag{4.116}$$

Table 4.3 shows the obtained mean squared error (MSE) of the quadratic regression models for the different weather stations for different seasons. It will be seen that the least average MSE is obtained for the Diyarbakir weather station, followed by the average of the three weather stations. Adiyaman weather station follows the average of weather stations on low MSEs; while, Sanliurfa weather station has the highest average MSE on all seasons. Table 4.4 show the coefficient of determination for the models, a parameter that estimates how much of variance between the independent and dependent variable explained by the models. Again, it will be seen that Diyarbakir weather station has the highest average coefficient of determination on all seasons, followed by average of the three weather stations and then Adiyaman weather station; Sanliurfa weather station has the lowest average coefficient of determination. A comparison of Table 4.1 and Table 4.3 shows that the quadratic models have lower MSEs as compared to the linear models. Also, the quadratic models have higher coefficients of determination as compared to the linear models. This observation is expected as the quadratic models should have more expressive power (flexibility) for fitting complex data as compared to linear models.

Table 4.3: Quadratic regression mean squared (MES) for different stations

Parameter/season	Winter	Spring	Summer	Autumn
Adiyaman	0.0642	0.0508	0.0413	0.0378
Diyarbakir	0.0370	0.0152	0.0126	0.0109
Sanliurfa	0.0718	0.0641	0.0441	0.0391
Mean (direct: m)	0.0526	0.0396	0.0327	0.0285
Mean (Thiessen polygon method: TPM)	0.0463	0.0345	0.0294	0.0206

Table 4.4: Quadratic regression model coefficient of determination (r2) for the different stations

Parameter/season	Winter	Spring	Summer	Autumn
Adiyaman	0.6781	0.6824	0.6872	0.6910
Diyarbakir	0.7858	0.7945	0.7955	0.7978
Sanliurfa	0.6542	0.6683	0.6708	0.6895
Mean (direct: m)	0.6973	0.7106	0.6984	0.7288
Mean (Thiessen polygon method: TPM)	0.7259	0.7511	0.7372	0.7446

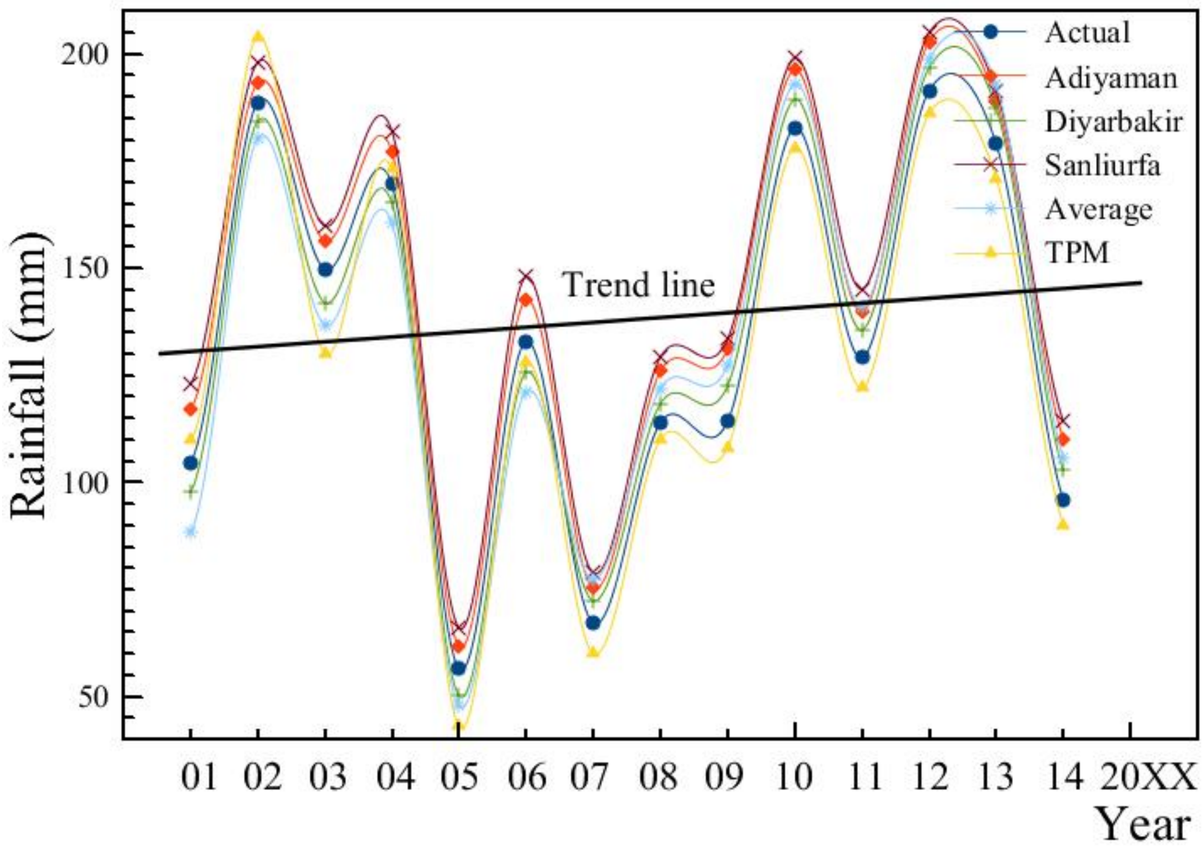

Figure 4.1: Models validation for winter seasons for the developed quadratic models

From Tables 4.1, 4.2, 4.3 & 4.4 it will be seen that the linear models are less suitable for the modelling of rainfall change; the quadratic models have better performance metrics. The developed models were achieved using rainfall data from 1963 – 2000. In order to observe the generalization capacity of the developed models, rainfall data from 2001 – 2014 were used to validate the models for the different seasons based on models developed for the different weather stations and the average of the weather stations data. For the quadratic models with good performance metrics, the graphs of models validations are shown in Figures 4.1 – 4.4.

From Figure 4.1, it will be seen that Diyarbakir weather station has the closest values (graph) to the actual rainfall data for the winter season. The Thiessen Polygon Method (TPM), average (direct mean), Adiyaman and Sanliurfa data models follow the Diyarbakir weather station model on estimation error respectively.

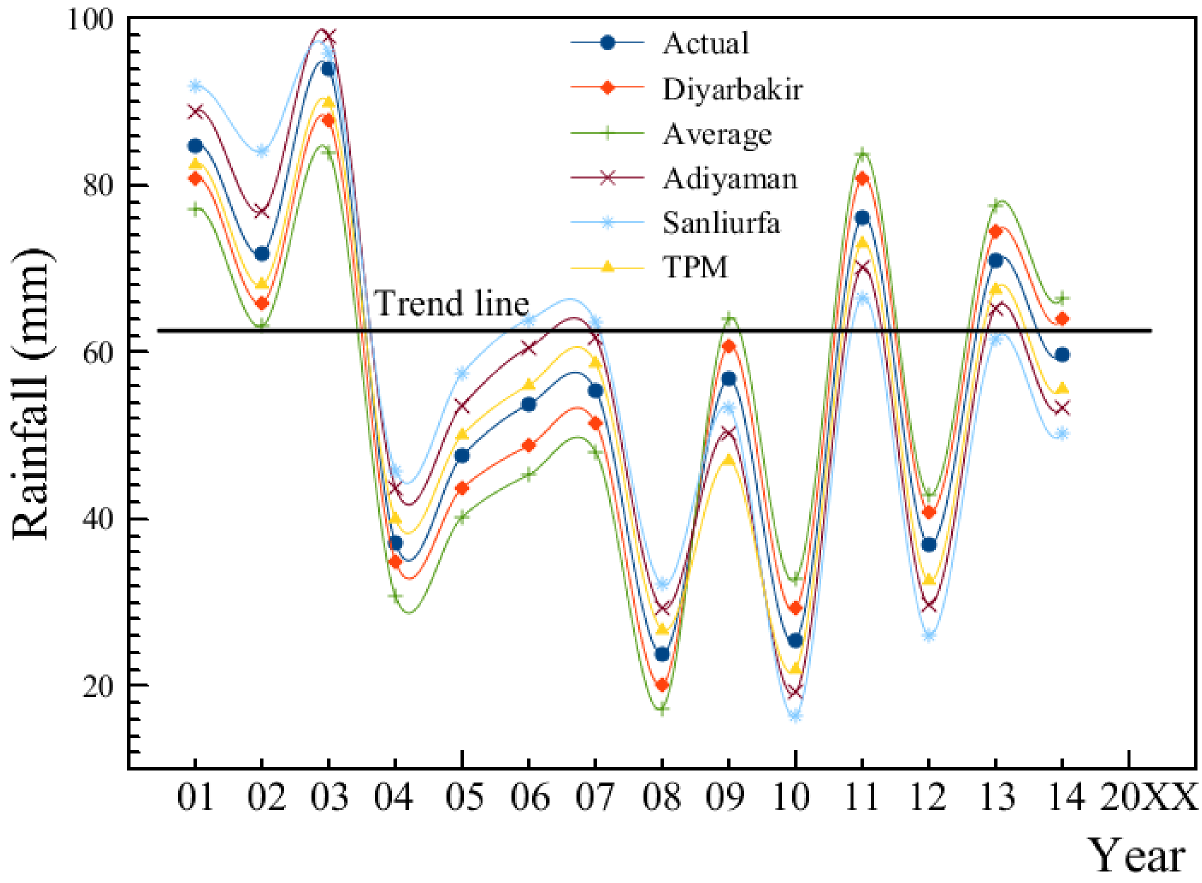

Figure 4.2: Models validation for spring seasons for the developed quadratic models

Similarly, from Figure 4.2, it will be seen that Diyarbakir weather station has the closest values (graph) to the actual rainfall data for the Spring season. The Thiessen Polygon Method (TPM), average (direct mean), Adiyaman and Sanliurfa data models follow the Diyarbakir weather station model on estimation error respectively.

However, from Figure 4.3, it will be seen that Thiessen Polygon Method (TPM) based model has the closest values (graph) to the actual rainfall data for the Summer season. The Diyarbakir weather station, average (direct mean), Adiyaman and Sanliurfa data models follow the Thiessen Polygon Method (TPM) based model on estimation error respectively.

From Figure 4.4, it will be that the Diyarbakir weather station again has the closest overall curve to the actual data, implying a good fit and generalization feature on the validation data. Also, the average of weather stations follows Diyarbakir weather on the validation fit and generalization feature. Adiyaman models validation performance follows the average of weather stations models and better than Sanliurfa weather station based models.

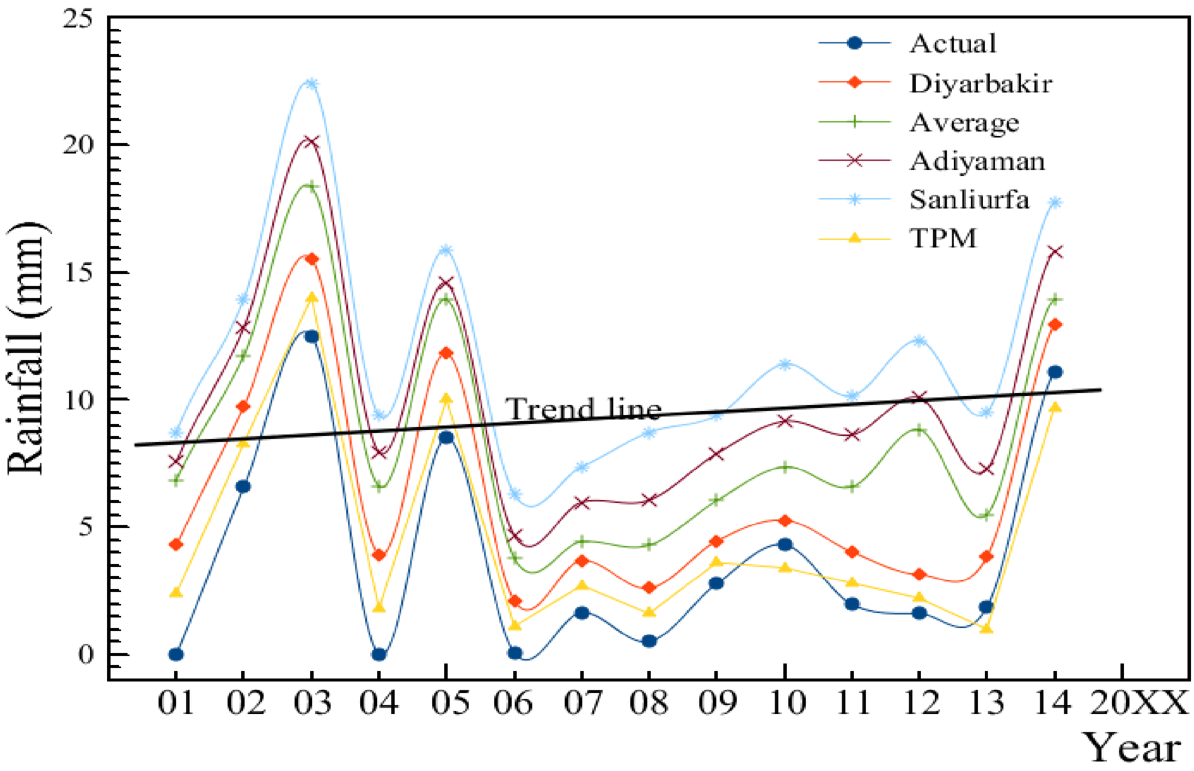

Figure 4.3: Models validation for summer seasons for developed quadratic models

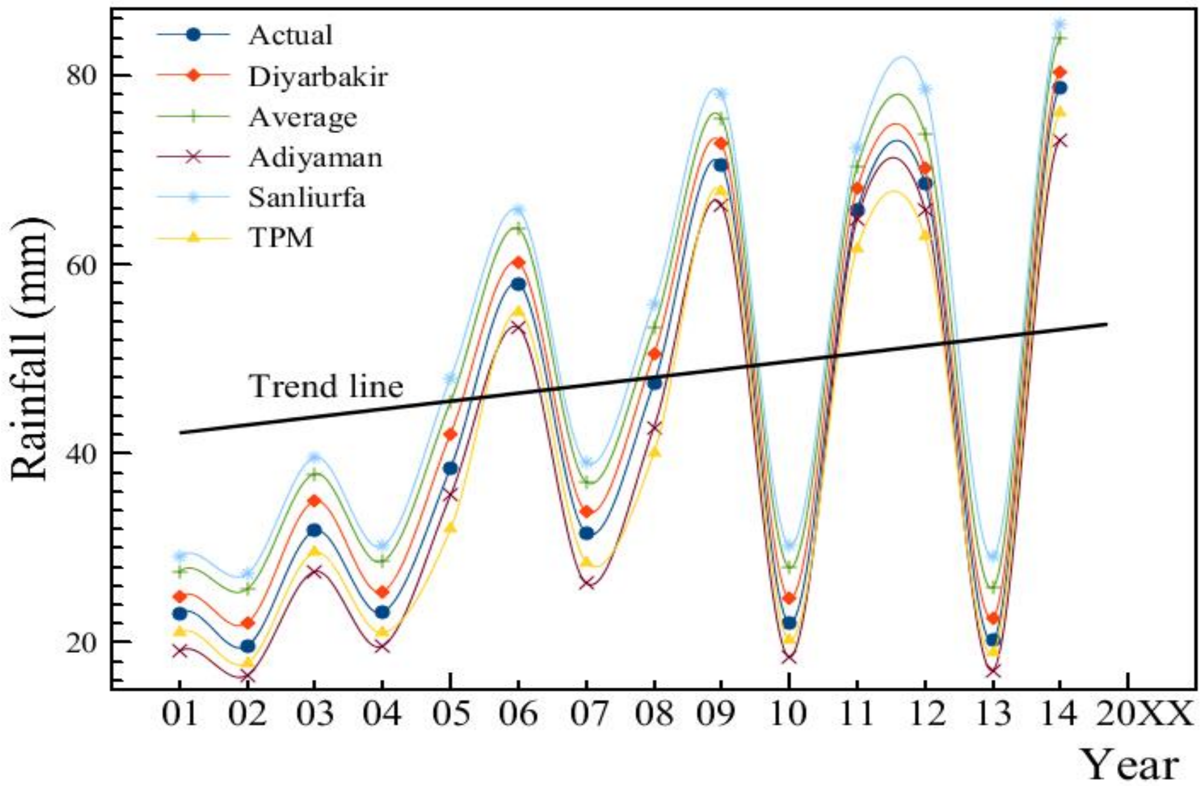

Figure 4.4: Models validation for autumn seasons for the developed quadratic models

4.2 Results Analysis and Discussion

In the previous section we discuss the testing results of the models developed on the remaining data (i.e. testing data) which are not part of the training data; that is, from 2001-2014. This allows the observation of the generalization capacity of the trained networks. The linear regression (LR) models were selected for testing alongside the quadratic regression models. The linear regression models were observed to have a higher mean squared error (MSE) as compared to the quadratic regression models on all of the three climate data modelling; hence, lesser accuracy on modelling the climate data. The relatively poor modelling capability of the linear regression models can be attributed to the non-linear nature of rainfall data. For better regression modelling, the order of the regression is increased to allow for a higher degree of freedom in sufficiently capturing data points. i.e. quadratic regression analysis.

Figure 4.1 seem to suggest that there is an overall gradual increase in the annual rainfall for winter seasons in the last few years. This observation is however not surprising, considering the presence of such a large dam as Ataturk dam in the region, as discussions in chapter 2 inform on the increased evapotranspiration as result of dam presence and operation in irrigation. From Figure 4.2, the rainfall for Spring seasons seems to fluctuate between 20mm and 80mm in the last few years. From Figure 4.3, rainfall seem to be somewhat regular from 2006 – 2013, but with a sudden rise in 2014. Figure 4.4 suggests that the variance of rainfall for Autumn seasons have been increasing for the past several years. i.e. 2001 – 2014.

4.3 Summary

This chapter details the modelling of Ataturk dam region climate data using multiple linear regression and quadratic regression. Climate data attributes which can be used for forecasting are considered for modelling using the aforementioned modelling tools. Firstly, parameters for linear regression models which allow reasonable data fitting are estimated. The statistical nature of quadratic regression allows a more accurate modelling of such non-linear climate data. Also, the aforementioned models are tested to ascertain that obtained mean square errors are within acceptable bounds for such an application as climate forecast.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This work revisits and re-examines the impact of dam construction and its running on the environment. While, the enormous benefits of dam operation abound, there have been many counter-arguments relating to the demerits of dam operation based on negative environment impacts. In this research, we begin with discussions on the motivations for dam construction and operation, looking at the different types in operation today. Going further, we give brief but sufficient discussions on practical siting, construction and operations of major dam types; specifically, discussion is given on the Ataturk dam in relation to environmental impacts, which has been used a case study within this work. Furthermore, regression analysis is employed for capturing statistical knowledge of climate data for regions around Ataturk dam, Adiyaman, Diyarbakir and Sanliufa; climate data was obtained from the Turkish State Meteorological Service (DMI). The important climate data for which the impacts of Ataturk dam is considered is rainfall. From the climate data obtained, we systematically evolve a simple time-series approach for modelling climate data. Particularly, we use the present year rainfall to predict or forecast the following year rainfall. The quadratic (higher order) regression models yielded relatively lesser mean squared error (MSE) as compared to the linear regression models. This is not surprising when linear regression analysis is employed for modelling a non-linear data such as climate data. The capability of linear regression analysis to capture sufficient statistical trends in such data is quite limited. Hence, the higher order polynomial regression models which have far superior capability for modelling highly non-linear data are of better performance. Also, analysis of simulated results suggests that over the life time of the Ataturk dam, there has been an appreciable overall increase in precipitation.

5.2 Recommendations

In this research, polynomial regression has been considered for modelling climate data, a relatively non-linear data. Taking the limited capability of regression analysis for model data which the linear association between independent variables and dependent variable cannot be ascertained, a worthy alternative is neural network, a non-parametric data modelling tool that has superior power in modelling highly non-linear data. Particularly, a type of neural network popular for time–series modelling and capturing statistical features in data, recurrent neural network, is suggested for modelling the climate data analysed in this research.

Furthermore, as against the employed neural network models, other machine learning models (or algorithms) such as regression support vector machine, regression decision tree, random forest, etc. can be considered. Also, using evolutionary computation techniques such as particle swarm optimization, ant bee colony, genetic algorithm for learning the weights of the employed neural networks within this work may yield improved performance.

Going further, the modelling results within this work show that region surrounding the Ataturk dam have an overall gradual increase in precipitation. I obvious that responsible governmental and non-governmental agencies should begin to look at ways to keep that good impact in such region where more rainfall is needed by increasing vegetation cover.

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