CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Several research works have been carried out to study the impact of land cover change on the hydrology of river basins. Land use and land cover change very often due to the growing population and economy. In human history land, a fundamental factor of production, has been coupled to economic growth (Richards, 1990). Land cover changes are controlled by human interactions. Land use affects land cover and changes in land cover affect land use. A change in either, however, is not necessarily the product of the other. Changes in land cover by land use do not necessarily imply a degradation of the land. However, many shifting land use patterns, driven by a variety of social causes, result in land cover changes that affect biodiversity, water and radiation budgets, trace gas emissions and other processes that, cumulatively, affect global climate and biosphere (Riebsame et al., 1994). The main factor that causes land use changes are human demand for physical resources, technological expansion and institutional capacity to produce and consume such resources. The rapidly increasing population pressure in many rural areas of
developing countries has often led to changes in land use in terms of deforestation, reclamation of wetlands, etc. mainly aiming at agricultural production. Neither population nor poverty alone constitute the sole and major underlying causes of land cover change world-wide (Lambin et al., 2001). Rather, responses of people to economic opportunities, as mediated by institutional factors, drive land cover changes. Opportunities and constraints for new land uses are created by local as well as national markets and policies. Global forces become the main determinants of land use change, as they amplify or attenuate local factors.

Monitoring of these changes and assessing the impacts are very critical for developmental plans (Krishna et al., 1999). LU/LC monitoring is an important aspect to determine the LU/LC change and likely impacts on the ecosystem (Eiumnoh et al., 1997) that often lead to several environmental impacts, such as soil erosion, soil moisture, soil nutrients, change in micro-climate and so forth. These impacts not only affect within the watershed boundary but also bring in several harmful effects downstream (Eiumnoh et al., 1997). Knowledge of LU/LC change is important for many planning and management activities (Lillesand and Kiefer, 1994). Technological, institutional and natural resource policy forces also play an important role in changing land use pattern (Rao and Pant, 2001). Therefore, knowledge of changes in LU/LC is becoming far more important from both ecological and economical point of view (Lucas and Molenaar, 1990).

Limitations of hydrological measurement techniques and a limited range of measurements in space and time are the main reasons to model the rainfall-runoff processes in hydrology (Beven, 2000). Everything we want to know in the hydrological cycle cannot be measured. Hence, we require to extrapolate our requirements from the available measurements and then arrive at the likely impact of future hydrological change. The assessment of the effects of LU/LC changes on water resources, runoff generation and floods is one of the recent areas of importance in hydrological modelling and is one of the main research topics in the last decade.
2.2 GIS based hydrological modelling

In modelling, the hydrological systems are processed based on their physical, chemical and/or biological governing laws. Several investigators (Snyder and Stall, 1965; Clarke, 1973; Miller and Woolhiser, 1975; Woolhiser, 1982; Chow et al., 1988; Somlyody and Varis, 1993) classified the hydrological models based on different criteria. This can be grouped as those based on randomness - deterministic/stochastic, spatial variation - lumped/distributed; space-independant/space-dependant, and time variation - steady flow/unsteady flow; time-independant/time correlated. Each of these modelling approaches has a role to play in hydrologic prediction. However, some are better suited than others to forecast a given hydrologic situation. In addition, the approaches have limitations, which relate to their power, utility, accuracy and ease of use (Woolhiser and Brakensiek, 1982; Vertessy et al., 1993).

Computer based hydrological models have been developed and applied at an ever increasing rate during the past four decades. The key reasons for that are twofold: (a) improved models and methodologies are continuously emerging from the research community, and (b) the demand for improved tools increases with the increasing pressure on water resources. Overviews of the status and development trends in catchment scale hydrological modeling during this period can be found in Fleming (1975) and Singh (1995).

GIS is a tool which can analyse and manage spatial data and hence, found much useful in the hydrological analysis. Bhaskar et al. (1992) utilised the GIS for the hydrologic parameter estimation for the geomorphologic instantaneous unit hydrograph of the watershed hydrology simulation model. Grenne and Cruise (1995) used GIS for urban watershed modelling. The primary role of GIS in hydrological modelling is to integrate the ever-increasing volumes of diverse spatial and non-spatial data. This can be the model input or output. Recent advances in GIS (hardware and software) technology offer unprecedented capabilities for storing and manipulating large quantities of detailed, spatially-distributed watershed data.
Hydrologic models with a spatial structure are being increasingly based on DEM or DTM (Moore et al., 1991). Many of the existing models, such as SHE, TOPMODEL etc., have been adapted to the new type of data that can be processed by GIS software. Integration of hydrologic models with remotely sensed, GIS and DEM-based data is becoming popular. Han (website) used multi-temporal remote sensing data to analyse the pattern of surface change of the city of Shanghai, Korea and its neighborhoods brought on by the sudden development of the city. The amount of surface change between 1979 and 2001 was found to be 20.40% and the increase in difference in temperature of the urban area and agricultural area was 0.37.

2.3 Land use/land cover changes and their impact on hydrology

Increased stress on the land due to population growth affects the hydrology of the area. The assessment of the effects of LU/LC changes on water resources, runoff generation and floods is often necessary in hydrological modelling and has gained considerable importance in the past decades. The hydrologic effects of land use changes have been described by Calder (1993). Land use change can have local, regional and global hydrologic consequences. On a global scale, the largest change in terms of land area and also in terms of hydrologic effects, is from afforestation and deforestation. Afforestation can affect annual flow, seasonal flow and flood. It also improves water quality and reduces soil erosion. Agricultural intensification alters transpiration rates and affects runoff. The drainage of wetlands and urbanisation are other land use changes with important hydrologic consequences. Urbanisation increases impervious land uses, reduces infiltration and causes more runoff and higher peak discharges.

Fongres and Fulcher (2002) in their study stress the importance of detention/retention structures to reduce the increased flow rates, stream bank erosion and to improve the water quality caused by urbanisation. A study conducted
by Noorazuan et al. (website) concludes that the landscape diversity of Langat River Basin, Malaysia, were significantly changed after 1980s and as a result, the changes also altered the Langat’s stream flow response. White and Greer (2002) from their studies infer that increasing urbanisation in the sub watershed of Los Penasquitos Creek, California has been shown to be associated with the significant hydrologic changes in the stream, the most obvious of which are increasing peak flood flows and dry season runoff. If the continued watershed urbanisation is projected to the future, the current hydrologic characteristics of the coastal streams will likely continue to change, and the aquatic and riparian-associated wildlife species that are favoured under these modified conditions will continue to increase at the expense of those species better suited to historic conditions.

The patterns of vegetation on land surface give areas with different runoff generating characteristics. The most obvious influence of land use on the water balance of a catchment is on the evapotranspiration process. Different land use types have different evapotranspiration rates, because different crops have different vegetation cover, leaf area indices, root depths and albedo. Also interception rates are different, although the influence of interception are noticeable only during small storms (Ward and Robinson, 1990). The idea that tress consumes more water than lower-growing vegetation is no longer in question (Bosch and Hewlett, 1982). Trimble et al. (1987) reported that a large part of the southeastern U. S., forested over a period of decades, have continued to transpire about 330 mm more than other land covers (Ward and Trimble, 2004).

Mathew (website) in his study concludes that the land use change of Pallipad, Ramankari and Kumarakom panchayats of the Kuttanad region clearly reveals the pattern and extent of land use changes, its causes and consequences. The major change is the conversion of rice fields to non-rice or non-agricultural purposes. The constraints in rice cultivation and the huge demand for land for non-agricultural purposes especially for settlements due to the population pressure should be taken in to account when an action plan is formulated. The qualitative
and quantitative aspects of the biophysical resources should be taken into account when we introduce a new land use pattern in the area. A substantial decline in the area under rice and cassava, besides increase in coconut and rubber cultivation are observed in Kerala (Kumar, 2005). The consequences of deforestation, which also have been widespread in the State, include frequent flash floods and landslides, soil erosion and silting of reservoirs, causing serious ecological and environmental problems and complex feedback effects on agricultural production. The land use in the western slopes of the Western Ghats in the Kottayam district of Kerala shows that the human encroachment is very high and this is evident from the large scale rubber plantation (76.49%) in comparison to the area under natural vegetation (5.68%) (Vijith and Satheesh, 2007). The information with regards to the extent and spatial distribution of distinct land use categories and geomorphological units is very useful for the evaluation and utilisation of natural resources for future development.

Computer simulation modeling has been used for at least 40 years to study the effects of land use changes within catchments (e.g., Onstad and Jamieson, 1970; Hillman and Verschuren, 1988; Bultot et al., 1990; Hernandez et al., 2000; Niehoff et al., 2002; Miller et al., 2002; Heuvelmans et al., 2005). Onstad and Jamieson (1970) presented one of the first attempts to use a hydrological model for predicting the effects of land use changes on runoff. They carried out sensitivity analyses to illustrate the hydrological response to various conservation practices. However, they had no data to validate the model on situations corresponding to changed land use conditions (Lorup et al., 1998). Similar approaches are reported for catchment studies in Thailand (Storm et al., 1987), Australia (Hookey, 1987), Belgium (Bultot et al., 1990), India (Jain et al., 1992) and Tanzania (Sandström, 1995), where hydrological models were used to simulate the effects of assumed or actual land use changes, but rigorous model validation has not been done to lack of data. Rigorous model validation procedures are required before the model capabilities can be assessed (Ewen and Parkin, 1996; Parkin et al., 1996; Lorup et al., 1998).
The influence of land use changes on runoff generation has been frequently studied in the last two decades using computer simulation models. Either distributed physically based rainfall-runoff models or conceptual rainfall-runoff models have been used by many researchers. Distributed physically based rainfall-runoff models use a large number of parameters, which are difficult to determine and the runoff generation processes are not described adequately. Conceptual rainfall-runoff models use less parameters but describe the rainfall-runoff processes with simple concepts. This simplification prevents to transfer measured physiographic properties and incorporate variables directly into the modelling parameters (Weiler et al., 2000). Lorup et al. (1998) adopted a methodology combining common statistical methods with conceptual hydrological modelling to distinguish between the effects of climate variability and the effects of land use for six semi-arid basins in Africa. Their analysis indicated a decrease in the low flow for most of the testing catchments located within communal land, where large increase in population and agricultural intensity have taken place. Nandakumar and Mein (1997) combined a Monte-Carlo simulation method with a conceptual rainfall-runoff model to examine the effects on random errors with conceptual model parameters on flood predictions.

The Soil and Water Assessment Tool (SWAT), which is used in this work, has also been used with good results for assessing land cover impacts on hydrology in several studies (e.g. Hernandez et al., 2000; Miller et al., 2002; Heuvelmans et al., 2005; Nelson et al., 2005; Santhi et al., 2006; Kaur et al., 2004; Tripathi et al., 2003; Vaché et al., 2003; Bracmort et al., 2006; Chaplot et al., 2004; Fohrer et al., 2002; 2005). SWAT is a basin-scale continuous-time model that operates on a daily time step and is designed to predict the impact of management on water, sediment and agricultural chemical yields in ungauged watersheds (Gassman et al., 2007). Hernandez et al. (2000) found that SWAT could accurately predict the relative impacts of hypothetical land use change in the 8.2 km² experimental sub watershed within the San Pedro watershed. Miller et al. (2002) describe simulated streamflow impacts with SWAT in response to historical land use shifts in the 3,150 km² San Pedro watershed in southern Arizona and the Cannonsville watershed in south central New York. Streamflows were predicted to increase in the San Pedro
watershed due to increased urban and agricultural land use, while a shift from agricultural to forest land use was predicted to result in a 4% streamflow decrease in the Cannonsville watershed. Increased streamflow was predicted with SWAT for the 59.8 km$^2$ Aar watershed in the German state of Hessen, in response to a grassland incentive scenario in which the grassland area increased from 20% to 41% while the extent of forest coverage decreased by about 70% (Weber et al., 2001). Heuvelmans et al. (2005) report that SWAT produced reasonable streamflow and erosion estimates for hypothetical land use shifts, which were performed as part of a life cycle assessment (LCA) of $CO_2$ emission reduction scenarios for the 29.2 km$^2$ Meerdaal watershed and the 12.1 km$^2$ Latem watersheds in northern Belgium. However, they state that an expansion of the SWAT vegetation parameter data set is needed in order to fully support LCA analyses. The impacts of hypothetical forest and other land use changes on total runoff using SWAT are presented by Lorz et al. (2007) in the context of comparisons with three other models.

Muttiah and Wurbs (2002) used SWAT to simulate the impacts of historical climate trends versus a 2040-2059 climate change projection for the 7,300 km$^2$ San Jacinto river basin in Texas. They report that the climate change scenario resulted in a higher mean streamflow due to greater flooding and other high flow increases, but that normal and low streamflows decreased. Gosain et al. (2006) simulated the impacts of a 2041-2060 climate change scenario on the streamflows of 12 major river basins in India, ranging in size from 1,668 to 87,180 km$^2$. Surface runoff was found to decrease, and the severity of both floods and droughts increased, in response to the climate change projection. An analysis of the impacts of 12 climate change scenarios on the water resources of the 18 major water resources regions in the U.S. was performed by Thomson et al. (2005) using the HUMUS approach, as part of a broader study that comprised the entire issue of volume 69 (number 1) of Climatic Change. Water yield shifts exceeding 50% were predicted for portions of Midwest and Southwest U.S., relative to the present water yield levels. Rosenberg et al. (1999) found that driving SWAT with a different set of 12 climate projections resulted in decrease in Ogallala Aquifer recharge of up to 77% within the Missouri and Arkansas-White-Red major water resources regions of the U.S.
Large scale LU/LC changes are taking place in Kerala State, which has an area of 38,863 km$^2$ and density of population of 819 per square kilometre. This change is mainly due to conversion of forests, mixed crop areas and also rice fields to plantation crops and urban areas. Therefore, the need to study the consequences of these LU/LC changes on the hydrology of this area was recognised. Not only in Kerala State but also in the entire humid tropical areas in south and south-east Asia these trends in change in LU/LC are noticed. It is in this background, the present study has been taken up in the Meenachil river basin of this humid tropical area, for which basin reliable hydrologic data for a few years are available and also data on LU/LC changes. Some of the existing mathematical tools and models have been attempted to achieve the objective of this study. The results of this study are expected to be of use to those involved in planning the development projects in this area.