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A digraph permanent approach to evaluation and analysis of integrated watershed management system

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SUMMARY

In the present study a deterministic quantitative model based on graph theory has been developed for the better development and management of watershed. Graph theory is an integrative systems approach to consider and model structural components of watershed management system along with the interrelationships between them concurrently and integratively. The factors responsible for the development of watershed system are identified. The degree of interaction between one subsystem with others are determined. The eigenvalue formulation is used to take care the inconsistencies arises due to inaccurate judgement in the degree of interaction between the subsystems. In this model the visual analysis is done to abstract the information using the directed graph or digraph. Then the matrix model is developed for computer processing. Variable permanent function in the form of multinomial represents the watershed system uniquely and completely by an index value. Different terms of the multinomial represent all possible subsystems of integrated watershed management system and thus different solutions for watershed management, leading to optimum solution. This index value is used to compare the suitability of the watershed with different alternatives available for its development. So the graph theory analysis presents a powerful tool to generate the optimum solutions for the decision maker for benefit of local people living in the watershed as well as the stakeholders. The proposed methodology is also demonstrated by a suitable example and is applied to the ecosystem and environment subsystem of the lake Qionghai watershed in China.

1. Introduction

Watershed is a topographically delineated area drained by a system of water bodies which become necessary to analyze for the sustainable development of the people living in that area. In recent decades, watershed management planning has been strongly influenced by the wide recognition of and concern for sustainable development (Bulkley, 1995; Slocombe, 1998; Radif, 1999). Management of a watershed is not restricted to only the surface water bodies but it includes the interaction of all the components within the watershed boundaries. The basic principle of watershed management is to use the land according to its capability and treat the land according to its need for sustainable development of the people living in that area (Rao and Kumar, 2004). Watersheds are complex systems incorporating many components including natural, economic, demographic and political factors (Wang et al., 2006). These subsystems interconnect and interact leading to four main characteristics of watershed systems: integrity, multiobjectives, dynamism, and uncertainty (Zou et al., 2000; Zhang et al., 2001).

Several studies have been conducted on integrated watershed management (Leach et al., 2002; Lee and Chung, 2007). Also several models have been developed for efficient management of the watershed (Wang et al., 2006; Arabi et al., 2007; Zoltay et al., 2010; Shi et al., 2012; Sanchez et al., 2014). Rao and Kumar (2004) presented a prototype spatial decision support system for watershed management which can help the end users in avoiding the laborious procedure of soil erosion calculations and analyzing various thematic layers to get suitable watershed management practices. Sanchez et al. (2014) used a spatial multifactor model and bivariate mapping to produce a novel assessment for watershed management, identification of vulnerable areas and allocation of resources. Shi et al. (2012) studied the impact of integrated small watershed management on soil erosion and sediment delivery in Three Gorges Area, China. Leach et al. (2002) formalized the concept of stakeholder partnership and proposed techniques for

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using interviews, surveys and documents to measure the six evaluation criteria and these criteria are applied to 44 watershed partnerships in California and Washington. They found that each criteria make a unique contribution to the overall evaluation. Zoltay et al. (2010) developed a generic integrated watershed management optimization model to efficiently screen a broad range of technical, economic and policy management options within a watershed system framework and select the optimal combination of management strategies and associated water allocations for designing a sustainable watershed management plan at least cost. Wang et al. (2006) used an interval fuzzy multiobjective programming method to solve an integrated watershed management problem for the lake Qionghai Watershed, China. Bhalla et al. (2011) analyze the suitability of Government of India's 2003 and 2008 common guidelines for prioritizing micro watersheds for restoration.

Digraph is a system approach and permanent matrix is used to study combinatorics. Variable permanent function integrates all the subsystems and their interactions with different attributes associated with them. This approach is a powerful integrative system approach to evaluate and analyze complex problems. It results in better understanding of system to take decision from all possible alternative solutions represented by terms of multinomial. Graph theory can be applied to water resource system for the sustainable development and management in terms of both quantity and quality in an integrative manner. A very few literatures are available on the application of graph theory in water resources development and management. Jacobs and Goulter (2007) and Mohan Kumar et al. (2008) applied the graph theory on water resources management in water distribution network. Ratha and Agrawal (2014) applied the graph theory in water resources development and management. Kumar et al. (2010) address the ecological and environment issue by developing different structural models using graph theory for effluent treatment system for electroplating. Some of the researchers have also applied the graph theory in different fields such as system wear evaluation and analysis (Gandhi and Agrawal, 1994), comparison and evaluation of various technical and economical features of wind, hydro and thermal power plants and their ranking according to their suitability index (Garg et al., 2006) as well as in manufacturing system management (Singh and Agrawal, 2008).

From the above literature review, it is found that a number of research work have been carried out for the development of some individual component of watershed. There is no methodology proposed to analyze a watershed using an integrated system approach which will help in improving the overall performance of a watershed. The integrated system approach considers the subsystems, their interactions, interdependencies and connectivities which are not found in literature. The proposed model based on the graph theory is capable to address the issue of integrative approach by considering all the subcomponents of watershed, their interaction and interdependencies and become a tool which will be useful for analyzing and evaluating the watershed system for its better management.

2. Identification of subsystem of watershed and their interaction

Any system can be represented by a mathematical model and to develop such type of mathematical model required the understanding of their structural constituents. In order to develop the mathematical model for the watershed management system the present paper identified 8 subsystems on which the development of watershed mainly depends. The literature review shows that very few authors have considered all the subsystems of watershed system for their study. Wang et al. (2006) divided the watershed system into six subsystems. They are (a) human population subsystem,(b) the agriculture subsystem,(c) the industry subsystem,(d) the tourism subsystem,(e) the nature resource subsystem,(f) the pollution subsystem. But in present study authors feel that the climate change and socio economic condition also affects on over all development of a watershed. The resources of a watershed generally get affected due to natural disasters such as flood, draught, cyclone andearthquake. So the disaster management is also a part of watershed development. The climate change is one of the factor for causing of disaster. Similarly the socio economic condition also plays a role for the overall development of a watershed system. Bhalla et al. (2011) also concluded that Criteria used to select micro-watersheds for hydrologic treatment should be re-formulated emphasizing efficient resource use and improved hydraulic function prior to social and economic concerns. Since the better management of watershed also depends on the socio economic of that area, the present paper considers the socio economic is also a subsystem of watershed.

The effective and efficient management of subsystems as well as the proper decision will help for better management of watershed system. Fig. 1 shows the tree diagram of watershed system which consists of the 8 subsystems.

*Human population sub system:*The population and its growth have various effects on the watershed. The requirement of water supply, quantity of waste water and solid waste generated, fulfilling of daily needs increase due to population and which affect largely on watershed.

Agriculture subsystem: Agricultural activities such as farming, forestry, fishing greatly affect the watershed. The water requirement for irrigation, use of fertilizer and chemicals increases due to increase in agricultural activity which affect greatly on watershed.

Industry subsystem: Industry is a major source of improvement of the economy as well as the developmental activities of an area. In the other hand it is also the main source of water and air pollution which will deteriorate the quality of life.

Tourism subsystem: The water requirement, waste water and solid waste generation, environmental degradation increases due to increase in number of tourists and at the same time the developmental activities, good infrastructure facilities generally come up in tourism area which will lead to a better quality of life.

Natural resources: Surface water, groundwater, land, minerals, forests are the major natural resources of a watershed. The development and proper utilization of natural resources are necessary for development of a watershed.

Ecosystem and environment: Water and air pollution, soil erosion, flood and unbalanced in the ecosystem is a great thereat to the watershed. The well balanced ecosystem can be achieved by various activities such as afforestation, wild life habitat and flood control which will help further development of the watershed.

Climate change: The average temperature, average precipitation etc of a watershed changes due to climate change and due to which the hydrology system of the watershed become unbalanced. Arabi et al. (2007) used SWAT for the analysis of watershed model which include weather, surface runoff, return flow, percolation, evapotranspiration (ET), transmission losses, pond and reservoir storage, crop growth and irrigation, groundwater flow, reach routing, nutrient and pesticide loads, and water transfer. This indicates that the climate change can affect the watershed.

Socio economic: The socio-economic development of a watershed depend a number of factors such as the policy adopted for development work, investment and benefit received by the local residents. The one of the specific goal of the Kentucky watershed management program was to preserve and enhance aesthetic and recreational values of watershed (Ormsbee and McAlister,