AGRICULTURAL WATER STRESS AND RISK ASSESSMENT USING INTEGRATION OF CATASTROPHE THEORY AND ENTROPY METHODS

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Specially dedicated to my parents, sister and husband, for their love and support

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ABSTRACT

Water is increasingly becoming a major constraint in agricultural development in many countries across the world. It is anticipated that global environmental change will deteriorate the condition further in near future. The objective of this research is to develop an evaluation approach for systematic assessment of spatial distribution of water stress and its risk to society in order to aid mitigation planning. Bangladesh is used as a case study in this research. Criteria based approach is used to select the water stress indicators. A data driven method is proposed through the integration of catastrophe theory and entropy methods for assigning weights to indicators for the estimation of water stress and its risk in a geographical information system (GIS). The novelty of the integrated method is that it can be used in multi-criteria decision making by avoiding personal judgment. Evaluation of the performance of the integrated method shows that it can predict water stress with an accuracy of 0.9, which is much higher than catastrophe (0.82) and entropy theory (0.8) based methods. Application of proposed method in Bangladesh reveals that about 5.7% area of the country is experiencing very high water stress, 32.1% area is high water stress, and the rest is moderate or no water stress for agriculture. Agriculture in western part of Bangladesh experiences more water stress compared to other parts of the country. The vulnerability map shows 25.1% area is very high vulnerable and 28.9% area is high vulnerable to water stress. The northwest region of the country is more vulnerable to water stress compared to other parts. Integration of water stress and vulnerability maps shows that northwest and southeast parts of Bangladesh have the highest risk to water stress. The analysis of the results reveal that higher agriculture water stress in northwest region resulted from water unavailability and in southwest region is closely related to poor water quality. The areas of highest water stress correspond very well with the areas that are usually thought as water scarce.

ABSTRAK

Air semakin menjadi kekangan utama dalam pembangunan pertanian di negara di seluruh dunia. Dijangkakan bahawa perubahan persekitaran global akan menyusutkan lagi keadaan di masa depan. Objektif kajian ini adalah untuk membangunkan satu pendekatan penilaian untuk taksiran sistematik taburan tegasan air dan risikonya kepada masyarakat untuk membantu dalam perancangan menangani isu kekurangan air. Bangladesh digunakan sebagai kajian kes dalam penyelidikan ini. Pendekatan berasaskan kriteria digunakan untuk memilih penunjuk tegasan air. Pendekatan pendorongan data dicadangkan menerusi integrasi teori 'catastrophe' dan kaedah 'entropy' dalam memberi penekanan kepada petunjuk bagi menentukan tegasan air dan risikonya dalam sistem maklumat geografi (GIS). Novelti kaedah integrasi ini, ia boleh digunakan dengan mengambilkira pelbagai keputusan kriteria untuk mengelakkan pertimbangan secara persendirian. Penilaian prestasi kaedah integrasi menunjukkan bahawa ia meramalkan ketegasan air dengan ketepatan 0.9, lebih tinggi daripada kaedah berasaskan teori 'catastrophe' (0.82) dan 'entropy' (0.8). Aplikasi kaedah yang dicadangkan di Bangladesh mendedahkan terdapat 5.7% kawasan negara yang mengalami tegasan air yang sangat tinggi, 32.1% kawasan dengan tegasan air tinggi, dan selebihnya sederhana atau tiada tegasan air untuk pertanian. Kawasan pertanian di Barat Bangladesh mengalami lebih tegasan air berbanding dengan bahagian lain. Peta keterdedahan menunjukkan 25.1% kawasan terdedah sangat tinggi dan 28.9% kawasan terdedah tinggi dengan tegasan air. Barat laut negara lebih terdedah kepada tegasan air berbanding dengan bahagian lain. Integrasi tegasan air dan peta keterdedahan menunjukkan bahagian Barat laut dan Tenggara Bangladesh memiliki risiko tertinggi terhadap tegasan air. Analisis keputusan menunjukkan bahawa tegasan air tinggi untuk pertanian di Barat laut adalah kerana ketiadaan air manakala di Tenggara berkaitrapat dengan kualiti air yang kurang baik. Kawasan yang mempunyai tegasan air tertinggi juga merupakan kawasan yang pada kebiasaannya memiliki air yang terhad.

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INTRODUCTION

1.1 Background of the Study

Ever-increasing demand for water in recent decades due to population growth, climate change and economic development caused water stress in many countries across the world in recent years (Halim, 2010; Wang et al., 2016). According to IFFRI (2012), nearly 2.4 billion people or 36% of the total global population are at present experiencing water stress. The global water demand will grow continuously with the growth of population as well as economic development (Anseeuw et al., 2012). It has been projected that the global population will be above 9.6 billion by 2050 (United Nations 2013). Global food production will require to increase by 70% to feed the growing population. This will cause of an enormous extension of global irrigated agriculture (FAO 2009). A rapid growth in agricultural activities will certainly increase the water demand for agricultural all over the world (Price et al., 2014; Wang et al., 2014). According to OECD (2012), the demand of global water may increase up to 55% within 2050, and the major increases will be in the developing countries which are currently facing water stress. As the availability of water is limited, the rising demand of water may make water resources more scarce (Schmitz et al., 2013; Wang et al. 2013). It has been projected that approximately 52% of the world's population will have been exposed to extreme water stress by 2050 (IFFRI, 2012). This will make water stress as the key problem of development in many countries across the world, if appropriate adaptation measures are not taken (Wang et al., 2014).

Many of the highly populated developing countries, like Bangladesh, Pakistan, Sri Lanka and India consume almost 85% of total water use for agricultural (Shahid et al., 2015). About 60-80% food production in those countries comes from irrigated agriculture. However, the available water per capita in many of those countries is lower than the average water available over the World (Sidhu, 2014). Furthermore, rapid depletion in water resource is going on due to global environmental changes as well as due to the mismanagement of this precious resource.

It is anticipated that increased temperature due to the changes in climate will change the magnitudes, intensities and frequencies of rainfall as well as its inter-annual variability and geographical distributions (Wang et al., 2014). Variability in the amount and distribution of rainfall may cause water stress, which in turn may limit crop yield (Basak, 2011). Understanding existing condition of water stress is essential for appropriate adaptation and mitigation planning in the context of environmental changes (Batisani and Yarnal, 2010, Shahid *et al.*, 2016).Thus, it is necessary to have a comprehensive assessment of current conditions water stress for sustainable management of water resources.

1.2 Problem Statement

Water stress encompasses different dimensions which need to be addressed clearly for its assessment (Forouzani & Karami, 2011). Water stress indices are generally used to evaluate the sustainability or stress in water resources. A number of water stress indices have been developed and successfully applied in different regions of world e.g. Falkenmarker indicator (Falkenmark, 1989), water poverty index (Sullivan, 2002), Canadian water sustainability index (CWSI, 2007) and watershed sustainability index (Chaves & Alipaz, 2007), etc. Although these indices have been successfully implemented in some regions or countries, they are not applicable to other regions and countries (Juwana, Perera, & Muttil, 2010). This emphasizes the need of a new approach for assessment of water stress applicable in a broader geographic context.

Two major steps are used to evaluate water stress using index base method namely, selection of suiindicators and assigning weights to indicators. Generally indicators and weights are selected or assigned by decision makers, which reflects the preference of decision maker in specific study or region (Ahmed et al., 2015; Al-Abedi and Shahid, 2015). Therefore, processes of indicator selection and weighting the indicators in most of the cases are usually inadequately systematic and transparent, which often results in a subjective decision and unsystematic conclusions (Wang et al., 2014).

Therefore, the major challenge in evaluation of water stress using index based approach is the selection of suiindicators in a transparent way and assigning weights by avoiding human preferences. This emphasizes the need to develop an approach for systematic selection of indicators and assigning weights objectively so that they can be used in a wide range of environmental assessment.

1.3 Research Objectives

The major objective of the research is to develop an approach for systematic assessment of spatial distribution of agricultural water stress and its risk in order to aid necessary adaptation and mitigation planning. The specific objectives are

1. To identify the suiindicators in a methodical way for assessment of geographic distribution of agricultural water stress, vulnerability and adaptation
2. To develop a data driven multi-criteria evaluation approach through integration of catastrophe and entropy theories for the unbiased assessment of spatial distribution of risk to agricultural water stress.

3. To apply the data driven multi-criteria evaluation approach for mapping agricultural water stress risk in Bangladesh.

1.4 Significance of the Study

A water stress index development approach is proposed to select indicators in a systematic way and assign weights mathematically. It can be expected that the proposed water stress indicator will be an important tool for the assessment of existing water stress as well as future water stress conditions in the context of changing environment. The application of proposed method will help the stakeholders and decision makers to take appropriate decisions and measures for the utilization of water and long term water planning in water stressed regions.

Agriculture is a decisive factor in the economy and politics in Bangladesh. However, knowledge on increasing water stress in agriculture of Bangladesh is not much clear to stakeholders and decision makers. It can be expected that the proposed study will help the policy makers and related organizations for adopting necessary adaptation measures.

1.5 Scope of the Study

The scopes of the study are

1. To assess agricultural water stress within the geographical boundary of Bangladesh
2. To assess agricultural water stress risk by considering spatial distribution of agricultural water stress, socio-economic vulnerability to water stress, and adaptation capacity to water stress.
3. To identify the water stress, vulnerability, and adaptability based on the different qualitative assessment method.

4. To identify the adaptation measures relevant to the socio-economic context of Bangladesh.

1.6 Research Hypothesis

1. How an index-based multi-criteria evaluation tool can be develop to avoid subjectivity in decision making.

2. How multi-criteria decision making tools can be used for the assessment of agricultural water stress in order to adapt with agricultural water stress.

1.7 Research Questions

1. The physical theory based weighting approach can reduce subjectivity in decision making and provide unbiased estimation of spatial distribution of water stress.

2. Systematic assessment of spatial distribution of agricultural water stress can help to identify the cause of water stress and adaptation measures to mitigate water stress

1.8 Outline Of The Thesis

The present thesis is organized in five chapters. Outline of the thesis is given below.

1. The background, objectives, significance and scopes of the study are discussed in Chapter 1

2. Literatures related to water stress and its assessment using index based approach is reviewed in Chapter 2.

3. The methodology developed to assess the geographic distribution of water stress risk is given in Chapter 3. Description of the study area and data used are also discussed in chapter 3.

4. The obtained results using the methodology proposed in Chapter 3 are presented in Chapter 4. The results are also analyzed in this chapter in order to derive possible adaptation methods.

5. The conclusions derived from the finding of the research and the future studies that can be envisaged from this study are mentioned in Chapter-5.

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