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SUMMARY OF DOCTORAL THESIS

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Title: Statistical analysis of seasonal rainfall variability in Ethiopia and its teleconnection with global sea surface temperatures

(エチオピアにおける降水量の季節変動の統計的解析と全球海面水温とのテレコネクション)

Ethiopia as one of the largest countries in Africa has an entire area of about 1.13 × 106 km^2 and extending from latitude 3° to 15° N and longitude 33° to 48° E. It is characterized by high complex of topography with high and lowlands, where the remarkable variations in elevation ranges from hundreds of meters below sea level at the northeastern areas to thousands of meters above sea level at the highlands of the northern parts. Ethiopia was affected by the Great Rift Valley that separated the country into two main plateaus (southeastern and western highlands) causing a high terrain complexity due to its extension from northeast to southwest of the country. The rift system has two flanks surrounded by southeastern highlands to the eastern flank and to the western flank are the western highlands with massive mountain ranges divided by steep and deep sided valleys of the main rivers, while the lowlands are located to the south and east of the southeastern highlands and to the west side of the western highlands.

On one hand, the country is distinguished by an essential amount of water resources and the majority of its river basins are derived from the high mountain ranges and are accelerated across systems of steep valley. On the other hand, the hydrological setting is highly variable in the region, where Ethiopia has twelve basins as following: (i) eight river basins; (ii) one lake basin (Lake Tana basin); (iii) the three other basins are dry. The river basins from the three main drainage systems are as follows;

1- The Nile basin including (Blue Nile or Abbay, Tekeze and Mereb, and Baro-Akobo) basins. The Nile Basin contributes about 85% of the Nile river annual flow and it covers about 33% of Ethiopia and it drains the northern and central regions westwards.

2- The Rift Valley basin including (Danakil, Awash, Central Lakes, and Omo-Gibe) basins. It represents about 28% of the Ethiopian area with a set of separate interior basins expanded from Djibouti in the north to the United Republic of Tanzania in the south, where about 50% of its total area is located in Ethiopia.

3- The South-East basin including (Ogaden, Genale-Dawa, Wabi-Shebelle) basins. About 39% of the country is covered by this basin and it drains the southeastern mountains towards the Indian Ocean and the Republic of Somalia.

The river basins originated from the western highlands flow towards the west into the basin system of the Nile River, the latter is passing through Sudan and Egypt and those derived from the eastern highlands flow easterly into the Republic of Somalia. The estimated potential of Ethiopian surface water of about 120 billion m3/year is derived from these twelve river basins. The majority (about 80%) of surface water, originating from the western and southeastern highlands with high rainfall amounts, is lost as runoff to the neighbor countries. Thus, Ethiopia represents the water tower for the Horn of Africa. The Ethiopian groundwater resources is low compared to the resources of surface water and its potentiality was estimated of about 2.6 billion m3/year. Thus, the country has the ability to irrigate about 5 million ha depending on these existing resources of water Furthermore, the estimated potential of the country's hydropower was about 45,000 MW. Nevertheless, such high potentials are not fully invested because of some technical challenges, limited resources of finance, and lack of decision makers in the government who have a perfect plan for utilizing these potentials. Consequently, Ethiopia has some obstacles to meet the increased demand for water supply, food, and energy because of the increasing rate of population, urbanization's rapid expansion and various economic activities.

The rainfall variability across time and space influences all aspects of human activities, especially socio-economic ones. Particularly, the rainfall over Ethiopia is characterized by high spatial and temporal variations due to complex topography (highlands and lowlands) and geographical location. The rainfall is considered to be the most crucial meteorological parameter in Ethiopia. Thus, these spatio-temporal variations are required to be fully investigated for many reasons; agriculture in Ethiopia is the major sector that mainly depends on rainfall with about 85% of labor force in the country, as well as the rainfall is vital for hydro power projects that accounts for about 98% of the energy production. One of the large-scale drivers affect rainfall over Ethiopia is Sea Surface Temperature (SST) and could be used as a key predictor that slowly changed. Three main seasons of rainfall over the country; summer rainy (June-September), winter dry (October-January), and spring mid-rainy (February-May) seasons. Most of the previous studies focused only on the main summer rainy season, while the spring rainfall was investigated in a few numbers of researches. Therefore, the main objective of this study is to present more investigation for spring rainfall, as well as summer rains over both local and large scales. Moreover, this study aims to improve our understanding for the teleconnection between SST and rainfall over Ethiopia. No doubt, the full investigation for this relationship will enhance the quality and accuracy of rainfall prediction models. Consequently, such accurate models would be beneficial for water sources management, development plans, addressing the hydrological extremes (flood and drought), and water allocation between Ethiopia and its downstream neighbors (Sudan and Egypt).

The first study focused on the statistical analysis of summer rainfall data (1985-2015) on a local-scale over Lake Tana. The latter is the main freshwater source for the Blue Nile River which contributes to about 60% of the Nile River flow. In addition, investigating the teleconnection between oceanic SSTs and summer rains over and counter and finally using the Artificial Neural Network (ANN) model for summer rainfall prediction over the basin. The summer rains over the basin extend from June to September (JJAS that is locally known as Kiremt). The basin was considered as one single area, where the results indicated that summer rains have a monomodal trend with a high peak in July/August. The interannual rainfall variability alternates between wet and dry with no significant change over time. The cross-correlation at a significance level of 0.05, indicated a significant teleconnection between oceanic SST and summer rains at a lead time of 4-5 months prior to the rainy season. Especially, two SST regions in the Pacific Ocean had such an impact on rainfall. Furthermore, these tele-connected areas were used as input data for prediction model of ANN. The final result showed that the ANN model would be skillful enough for enhancing rainfall prediction over the basin, as it enhanced the correlation between summer rainfall and SST data for about 0.8.

The second study aimed to expand the investigation about the influence of SST on rainfall from basin local size (Lake Tana) to the countrywide (Ethiopia). Moreover, both summer and spring rainy seasons were addressed. The long-term data for 65 years of summer rains and 50 years of spring rainfall were used. The results indicated the bimodal rainfall trend over the country with two peaks in July/August and April/May for summer and spring seasons, respectively. The regionalization of the country was crucial due to high spatio-temporal interdecadal rainfall variability. Ethiopia was divided into 14 rainfall zones in this study, 9 summer zones and 5 spring zones. The results of cross-correlations (significance level of 0.01) between SSTs and seasonal rainfall showed the influence of SST of Pacific, Indian, and Northern Atlantic Oceans and the Gulf of Guinea on the two seasons of rainfall over the country. In particular, SST regions over the Pacific and northern Atlantic Oceans had a significant teleconnection (remote link) with summer and spring rain peaks at a lead time of 5-6 and 6-7 months, respectively.