MAPPING OF FOREST WATER-STRESSED CHANGES BASED ON NORMALIZED DIFFERENCE WATER INDEX (NDWI) DURING 1998-2018 USING MULTI-TEMPORAL LANDSAT DATA

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ABSTRACT

Forests play an important role in ecosystem and its services by way of regulating the climate of the particular region. However, when the climate turns adverse changes begin to occur that cloud affect the status of the forest. There are several issues that are of global concern especially relating to the determination of the forest resources. Therefore this study maps the wetness of the Kota Tinggi forest reserve and vicinity using Landsat Multitemporal remote sensing image data. The specific objectives are :i) examine and analyse selective Normalized Difference Water Index (NDWI) method for humid tropic; and ii) map spatio-temporal pattern of NDWI in normal and extreme seasons. Multi-temporal images of three different epochs were used in this study, which include Landsat TM of 1998, 2008, and 2018. The normalize difference water indexes for each season was calculated and classified forest map of the study area was overlaid on the water indexes to find out the best wetness indexes within the period of the study as it relate with period of extreme climate condition such as La Nina and El Nino cases the result indicate that the hypothesis drawn H1: $\mu 1 = \mu 2$ pc 0.05 and H2:$\mu 1 \neq \mu 2$ pc>0.05. From the stated hypothesis, the result reveal that forest wetness has no relationship with the El Nino and La Nina, $R^2 = 0.0285$ and 0.0942 respectively. This is due to normal rainfall which has insignificant impact to La Nina and El Nino occurrences, couple with some environment factors influencing the structure of the study area.

ABSTRAK

Hutan memainkan peranan penting dalam ekosistem dan perkhidmatannya dengan cara mengawal iklim rantau ini. Bagaimanapun, apabila iklim berubah menjadi perubahan yang buruk mole berlaku awan mempengaruhi status hutan. Terdapat beberapa isu yang menjadi perhatian global terutama yang berkaitan dengan penentuan sumber hutan. Oleh itu kajian ini memaparkan kelembapan hutan simpan dan kawasan hutan Kota Tinggi menggunakan data imej penderiaan jauh Landsat Multitemporal. Objektif khusus adalah: i) meneliti dan menganalisis kaedah Indeks Perbezaan Air Teragih (NDWI) terpilih untuk tropika lembap; dan ii) peta spasi-temporal NDWI pada musim biasa dan melampau. Imej pelbagai zaman tiga zaman yang berlainan telah digunakan dalam kajian ini, yang termasuk Landsat TM pada tahun 1998, 2008 dan 2018. Menormalkan indeks air yang berubah-ubah untuk setiap musim telah dikira dan diklasifikasikan peta hutan kawasan kajian telah dilapisi pada indeks air untuk mengetahui indeks ketuhar yang terbaik dalam tempoh kajian kerana ia berkaitan dengan keadaan iklim yang melampau seperti La Nina dan El Nino kes hasil menunjukkan bahawa hipotesis yang ditarik H1: $\mu 1 = \mu 2$ pc 0.05 dan H2: $\mu 1 \neq \mu 2$ pc> 0.05. Dari hipotesis yang dinyatakan, hasilnya menunjukkan bahawa kebun hutan tidak mempunyai hubungan dengan El Nino dan La Nina, R2 = 0.0285 dan 0.0942 masing-masing. Ini disebabkan oleh hujan biasa yang mempunyai kesan yang tidak ketara kepada kejadian La Nina dan El Nino, pasangan dengan beberapa faktor persekitaran yang mempengaruhi struktur kawasan kajian.

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LIST OF ABBREVIATIONS

DEM	-	Digital Elevation Model
ETM+	-	Enhanced Thematic Mapper
GCP	-	Ground Control Point
NDWI	-	Normalized Difference Water Index
RS	-	Remote Sensing
NE	-	North East
SW	-	South West
NDVI	-	Normalized Difference Vegetation Index
ANN	-	Artificial Neural Network
GA	-	Genetic Algorithm
PSO	-	Particle Swarm Optimization
ARV	-	Atmospherically Resistant Vegetation Index
TM	-	The Thematic Mapper

LIST OF SYMBOLS

δ	-	Minimal error
d	-	Distance
F	-	Force
Km^2	-	Kilometre Square
Km	-	Kilometre
r	-	Radius

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Forests are playing a vital role in ecosystem services as they provide habitation for a variety of living organisms, and at the same time they are serving as climate regulators since they reserve water for some time. The forests are declining globally, in both regions that are water-limited and those that are experiencing excessive rainfall and exceptional rainy events (Rozas and García-González, 2012, Ghiyamat et al., 2015). This is partly due to natural factors such as climate change and partly due to anthropogenic activities such as logging and other developmental processes (Venter et al., 2016, Bennie et al., 2015), which in turn leading to forest wetness changes. Investigating forest-related water stress dynamics is very crucial for decision making in ecosystem conservation and management. In previous studies, environmental changes around the globe such as greenhouse gas emission, climate changes, loss of soil and biodiversity have been linked to changes in surface wetness (Wu et al., 2012, Rozas and García-González, 2012, Gopal, 2013, Gopal et al., 2015, Stancalie and Serban, 2014, Zhang et al., 2013). Similarly, majority of areas in the terrestrial earth surface such as forests have been experiencing these changes (Venter et al., 2016, Bennie et al., 2015). With the rapid economic advancements, forest cover changes are more prompt and various change detection methods were proposed (Homer et al., 2015, Tewkesbury et al., 2015, Ramirez et al., 2018, Hou et al., 2018). It is conceivable to establish suitable method for investigation of forest wetness changes over a given period, which could offer basis for effective and scientific approach to ecological restoration in an investigation area. Consequently, accurate and updated information is required for comprehending and evaluating forest wetness changes. Remote sensing images can offer an excellent data source as they record the condition

of forests over time (Liping et al., 2018, Lausch et al., 2018), from which the forest wetness pattern could be extracted and analyzed (Kirchhoefer et al., 2017).

Today, remote sensing has turn to a quotidian approach for monitoring surface wetness changes, since the acquired data can offer dynamic, periodic, macroscopic and economical information that is significantly diverse from conventional methods (Chen et al., 2004, Du et al., 2011, Feng et al., 2012, Blackmore, 2016). Several methods, such as spectral water indexes (Xie et al., 2014, Yao et al., 2015, Li et al., 2016), supervised and unsupervised classifications (Huang et al., 2014b, Huang et al., 2014a), and single band density slicing (Work Jr and Gilmer, 1976) were proposed for the extraction of surface wetness from different remotely sensed images.

In recent times, different water indexes have been developed, which include the Normalized Difference Water Index (NDWI) proposed by Gao (1996) using near- and shortwave-infrared bands of remotely sensed images. To compliment that, McFeeters (1996) proposed his NDWI using green and near-infrared bands, assuming that the wetted surface has low radiation and high absorbability, ranging from visible to infrared wavelengths. Although, NDWI is sensitive to built-up areas leading to over-estimation of surface wetness but it is still considered more reliable among all existing surface wetness mapping approaches as it has low computational cost, which at the same time makes it more efficient and user friendly (Du et al., 2016). In addition, it can effectively enhance the surface wetness information in many instances. Literature reveals that the McFeeters' method is not much appropriate for canopy-based water stress studies, which informed the selection of NDWI for this study NDWI due to its effectiveness in detection of vegetation liquid water instead of open water (McFeeters, 2013, Memon et al., 2015, Xu, 2006, Soti et al., 2009). In this study, the NDWI was derived from Landsat satellite data and used to investigate forest wetness changes in Kota Tinggi of Johor State, Malaysia.

1.2 Problem Statement

Extreme temperature and fluctuating rainfall could modify the structure, composition and distribution of forests in several regions across the globe (Pellizzari et al., 2016, Young et al., 2017, Martínez-Vilalta and Lloret, 2016, Stephenson et al., 2018). Rapid population growth and other anthropogenic activities are believed to be among the major contributors to climate change, which may in turn affect forest cover patterns over time (Crutzen, 2016, Forman, 2014, Musa et al., 2017b). Since monitoring forest changes are some of the essential information required for ecosystem conservation and management, study in this area remains an on-going topic.

Recent advancement in satellite remote sensing facilitates the acquisition and processing of geospatial data for a variety of study (Musa et al., 2018, Hashim et al., 2018). For instance, Normalized Difference Water Index (NDWI) has been extensively used for the extraction of surface wetness from different remotely sensed images (Du et al., 2016, Memon et al., 2015, McFeeters, 2013). Two prominent impacts of climate change to forest, namely the increase of temperature and rainfall intensity (droughts in El-Nino and excess in case of La-Nina), have been causing complex changes to forest growth and ecology, including the moisture content (canopy and soil) that in-turn have reverberations on water resources (Garreaud et al., 2017, Frank et al., 2015). However, analyzing the changes and related anomalies against the rainfall information is given less concern by the research community. Hence, remote sensing technique – the NDWI and related moisture indices could best be used for mapping long-term changes of forest-related water stress.

1.3 Research Hypothesis

H_o: forest wetness has no relationship with El Nino and La Nina event

H_a: forest wetness has a relationship El Nino and La Nina event The questions set to answer the objectives of the study include:

i. How can the forest wetness changes using normalized difference water index (NDWI) be examined and analyzed? and
ii. To what extend spatio-temporal map of NDWI change the forest pattern?

1.4 Objectives of the Study

The aim of this study is to map forest wetness changes using multi-temporal RS techniques. The specific objectives are as follows:

i. To examine and analyze selective NDWI method for humid tropic

ii. To map spatio-temporal pattern of NDWI for the normal and extreme seasonal cases (La Nina and El-Nino periods).

1.5 Scope of the Study

The scope of the study is as follows:

i. Multi-temporal Landsat TM satellite images of five periods (1998, 2008 2013, 2016 and 2018) were used in this study. The Landsat imagery was chose because it is widely recognized for its long term comprehensive archiving and availability for scientific studies.

ii. The forest wetness changes obtained with NDWI was used to assess the water stress within the Federal forest, Primary forest, and Secondary forest and Flood forest in other to ascertain the extent to which wetness variations within forest types are essential for analyzing the NDWI range against the forest wetness changes.

REFERENCES

ABDOLRAHIMI, M. 2016. *The effect of El Niño Southern Oscillation (ENSO) on world cereal production.* University of Sydney.

AL-SHALABI, M., BILLA, L., PRADHAN, B., MANSOR, S. & AL-SHARIF, A. A. 2013. Modelling urban growth evolution and land-use changes using GIS based cellular automata and SLEUTH models: the case of Sana'a metropolitan city, Yemen. *Environmental earth sciences,* 70**,** 425-437.

ANDERSON, J., HARDY, E., ROACH, J. & WITNER, R. A. 1976. *Land Use and Land Cover Classification System for Use with Remote Sensor Data; US Geological Survey Professional Paper 964,* Washington, DC, US Government Printing Office.

BARNARD, P. L., SHORT, A. D., HARLEY, M. D., SPLINTER, K. D., VITOUSEK, S., TURNER, I. L., ALLAN, J., BANNO, M., BRYAN, K. R. & DORIA, A. 2015. Coastal vulnerability across the Pacific dominated by El Nino/Southern oscillation. *Nature Geoscience,* 8**,** 801.

BARROS, N., COLE, J. J., TRANVIK, L. J., PRAIRIE, Y. T., BASTVIKEN, D., HUSZAR, V. L., DEL GIORGIO, P. & ROLAND, F. 2011. Carbon emission from hydroelectric reservoirs linked to reservoir age and latitude. *Nature Geoscience,* 4**,** 593–596.

BASTAWESY, M. E. 2014. Hydrological scenarios of the Renaissance Dam in Ethiopia and its hydro-environmental impact on the Nile downstream. *Journal of Hydrologic Engineering,* 20**,** 04014083.

BASTAWESY, M. E., RAMADAN ALI, R., FAID, A. & OSTA, M. E. 2013. Assessment of waterlogging in agricultural megaprojects in the closed drainage basins of the Western Desert of Egypt. *Hydrology and Earth System Sciences,* 17**,** 1493-1501.

BATOOL, S., KHAN, K., GHAFFAR, A. & HUSSAIN, S. 2015. FOREST COVER CHANGE DETECTION AND ITS IMPACT ON RAINFALL PATTERNIN THAK VALLEY (PAKISTAN). *Pakistan Journal of Science,* 67**,** 1-8.

BELLENGER, H., GUILYARDI, É., LELOUP, J., LENGAIGNE, M. & VIALARD, J. 2014. ENSO representation in climate models: from CMIP3 to CMIP5. *Climate Dynamics,* 42**,** 1999-2018.

BENNIE, J., DUFFY, J. P., DAVIES, T. W., CORREA-CANO, M. E. & GASTON, K. J. 2015. Global trends in exposure to light pollution in natural terrestrial ecosystems. *Remote Sensing,* 7**,** 2715-2730.

BLACKMORE, D. S. 2016. Use of Water Indices Derived from Landsat OLI Imagery and GIS to Estimate the Hydrologic Connectivity of Wetlands in the Tualatin River National Wildlife Refuge.

BUKATA, R. P., JEROME, J. H., KONDRATYEV, A. S. & POZDNYAKOV, D. V. 2018. *Optical properties and remote sensing of inland and coastal waters*, CRC press.

BUTLER, A. H., POLVANI, L. M. & DESER, C. 2014. Separating the stratospheric and tropospheric pathways of El Niño–Southern Oscillation teleconnections. *Environmental Research Letters,* 9**,** 024014.

CAI, W., BORLACE, S., LENGAIGNE, M., VAN RENSCH, P., COLLINS, M., VECCHI, G., TIMMERMANN, A., SANTOSO, A., MCPHADEN, M. J. &

WU, L. 2014. Increasing frequency of extreme El Niño events due to greenhouse warming. *Nature climate change,* 4**,** 111.
CAI, W., SANTOSO, A., WANG, G., YEH, S.-W., AN, S.-I., COBB, K. M., COLLINS, M., GUILYARDI, E., JIN, F.-F. & KUG, J.-S. 2015. ENSO and greenhouse warming. *Nature Climate Change,* 5**,** 849.
CAMPBELL, J. B. & WYNNE, R. H. 2011. *Introduction to remote sensing,* Guilford Press.
CASHIN, P., MOHADDES, K., RAISSI, M. & RAISSI, M. 2014. The differential effects of oil demand and supply shocks on the global economy. *Energy Economics,* 44**,** 113-134.
CHAVEZ, P. S. 1988. An improved dark-object subtraction technique for atmospheric scattering correction of multispectral data. *Remote sensing of environment,* 24**,** 459-479.
CHEN, Q., ZHANG, Y., EKROOS, A. & HALLIKAINEN, M. 2004. The role of remote sensing technology in the EU water framework directive (WFD). *Environmental Science & Policy,* 7**,** 267-276.
COBB, K. M., WESTPHAL, N., SAYANI, H. R., WATSON, J. T., DI LORENZO, E., CHENG, H., EDWARDS, R. & CHARLES, C. D. 2013. Highly variable El Niño–Southern Oscillation throughout the Holocene. *Science,* 339**,** 67-70.
COLWELL, R. N. 1997. History and place of photographic interpretation. *In:* PHILIPSON, W. R. (ed.) *Manual of photographic interpretation.* 2nd ed. Maryland, MD: American Society for Photogrammetry and Remote Sensing.
CONGALTON, R. G., ODERWALD, R. G. & MEAD, R. A. 1983. Assessing Landsat classification accuracy using discrete multivariate analysis statistical techniques. *Photogrammetric Engineering and Remote Sensing,* 49**,** 1671-1678.
CRUTZEN, P. J. 2016. Geology of mankind. *Paul J. Crutzen: A Pioneer on Atmospheric Chemistry and Climate Change in the Anthropocene.* Springer.
DADRAS, M., SHAFRI, M., ZULHAIDI, H., AHMAD, N., PRADHAN, B. & SAFARPOUR, S. 2014. Land use/cover change detection and urban sprawl analysis in Bandar Abbas City, Iran. *The Scientific World Journal,* 2014**,** 1-12.
DANLADI BELLO, A.-A., HASHIM, N. B. & MOHD HANIFFAH, M. R. 2017. Predicting Impact of Climate Change on Water Temperature and Dissolved Oxygen in Tropical Rivers. *Climate,* 5**,** 58.
DE LA ROSA-VELÁZQUEZ, M. I., ESPINOZA-TENORIO, A., DÍAZ-PERERA, M. Á., ORTEGA-ARGUETA, A., RAMOS-REYES, R. & ESPEJEL, I. 2017. Development stressors are stronger than protected area management: A case of the Pantanos de Centla Biosphere Reserve, Mexico. *Land Use Policy,* 67**,** 340-351.
DEMIR, S. & DEMIREL, Ö. 2016. Analysis Temporal Land Use/Land Cover Change Based on Landscape Pattern and Dynamic Metrics in Protected Mary Valley, Trabzon from 1987 to 2015. *Environmental Sustainability and Landscape Management***,** 291.
DEZHKAM, S., JABBARIAN AMIRI, B., DARVISHSEFAT, A. A. & SAKIEH, Y. 2017. Performance evaluation of land change simulation models using landscape metrics. *Geocarto International,* 32**,** 655-677.
DING, J., JIANG, J., FU, L., LIU, Q., PENG, Q. & KANG, M. 2015. Impacts of Land Use on Surface Water Quality in a Subtropical River Basin: A Case

Study of the Dongjiang River Basin, Southeastern China. *Journal Of Water,* 7**,** 4427-4445.
DU, Y., XUE, H.-P., WU, S.-J., LING, F., XIAO, F. & WEI, X.-H. 2011. Lake area changes in the middle Yangtze region of China over the 20th century. *Journal of Environmental Management,* 92**,** 1248-1255.
DU, Y., ZHANG, Y., LING, F., WANG, Q., LI, W. & LI, X. 2016. Water bodies' mapping from Sentinel-2 imagery with modified normalized difference water index at 10-m spatial resolution produced by sharpening the SWIR band. *Remote Sensing,* 8**,** 354.
EASTMAN, J. R. 2012. *IDRISI selva: guide to GIS and image processing,* Worcester, MA, Clark Labratories, Clark University.
EL-HALLAQ, M. A. & HABBOUB, M. O. 2014. Using GIS for Time Series Analysis of the Dead Sea from Remotely Sensing Data. *Open Journal of Civil Engineering,* 4**,** 386-396.
ELZ, I., TANSEY, K., PAGE, S. E. & TRIVEDI, M. 2015. Modelling deforestation and land cover transitions of tropical peatlands in Sumatra, Indonesia using remote sensed land cover data sets. *Land,* 4**,** 670-687.
FENG, L., HU, C., CHEN, X., CAI, X., TIAN, L. & GAN, W. 2012. Assessment of inundation changes of Poyang Lake using MODIS observations between 2000 and 2010. *Remote Sensing of Environment,* 121**,** 80-92.
FIELD. 2013. *Guide for REDD-plus negotiators August 2013* [Online]. Foundation for International Environmental Law and Development [Online]. Available at: http://theredddesk.org/sites/default/files/resources/pdf/2013/eng_guide_field.pdf [Accessed: 9 May 2017]. [Accessed].
FOODY, G. M. 2002. Status of land cover classification accuracy assessment. *Remote sensing of environment,* 80**,** 185-201.
FORMAN, R. 2014. *Land Mosaics: The Ecology of Landscapes and Regions 1995,* Springer.
FRANK, D., REICHSTEIN, M., BAHN, M., THONICKE, K., FRANK, D., MAHECHA, M. D., SMITH, P., VAN DER VELDE, M., VICCA, S. & BABST, F. 2015. Effects of climate extremes on the terrestrial carbon cycle: concepts, processes and potential future impacts. *Global Change Biology,* 21**,** 2861-2880.
GAO, B.-C. 1996. NDWI—A normalized difference water index for remote sensing of vegetation liquid water from space. *Remote sensing of environment,* 58**,** 257-266.
GAO, Z., ZHANG, L., ZHANG, X., CHENG, L., POTTER, N., COWAN, T. & CAI, W. 2016. Long-term streamflow trends in the middle reaches of the Yellow River Basin: detecting drivers of change. *Hydrological Processes,* 30**,** 1315-1329.
GARREAUD, R. D., ALVAREZ-GARRETON, C., BARICHIVICH, J., BOISIER, J. P., CHRISTIE, D., GALLEGUILLOS, M., LEQUESNE, C., MCPHEE, J. & ZAMBRANO-BIGIARINI, M. 2017. The 2010-2015 megadrought in central Chile: impacts on regional hydroclimate and vegetation. *Hydrology & Earth System Sciences,* 21**,** 6307-6327.
GATEAU-REY, L., TANNER, E. V., RAPIDEL, B., MARELLI, J.-P. & ROYAERT, S. 2018. Climate change could threaten cocoa production: Effects of 2015-16 El Niño-related drought on cocoa agroforests in Bahia, Brazil. *PloS one,* 13**,** e0200454.

GHIYAMAT, A., SHAFRI, H., MAHDIRAJI, G., ASHUROV, R., SHARIFF, A. & MANSOUR, S. 2015. Airborne hyperspectral discrimination of tree species with different ages using discrete wavelet transform. *International Journal of Remote Sensing,* 36**,** 318-342.

GILMORE, S., SALEEM, A. & DEWAN, A. 2015. Effectiveness of DOS (Dark-Object Subtraction) method and water index techniques to map wetlands in a rapidly urbanizing megacity with Landsat 8 data. *Research @ Locate in Conjunction with the Annual Conference on Spatial Information in Australia and New Zealand.* Brisbane, QLD, Australia.

GOPAL, B. 2013. Future of wetlands in tropical and subtropical Asia, especially in the face of climate change. *Aquatic sciences,* 75**,** 39-61.

GOPAL, B., SHETTY, A. & RAMYA, B. 2015. Prediction of the presence of topsoil nitrogen from spaceborne hyperspectral data. *Geocarto International,* 30**,** 82-92.

GRADWOHL, J. & GREENBERG, R. 2013. *Saving the tropical forests,* Routledge.

HAM, Y.-G., KUG, J.-S., PARK, J.-Y. & JIN, F.-F. 2013. Sea surface temperature in the north tropical Atlantic as a trigger for El Niño/Southern Oscillation events. *Nature Geoscience,* 6**,** 112.

HANLEY, D. E., BOURASSA, M. A., O'BRIEN, J. J., SMITH, S. R. & SPADE, E. R. 2003. A quantitative evaluation of ENSO indices. *Journal of Climate,* 16**,** 1249-1258.

HASHIM, M., MISBARI, S. & POUR, A. B. 2018. Landslide mapping and assessment by integrating Landsat-8, PALSAR-2 and GIS techniques: a case study from kelantan state, peninsular Malaysia. *Journal of the Indian Society of Remote Sensing,* 46**,** 233-248.

HOMER, C., DEWITZ, J., YANG, L., JIN, S., DANIELSON, P., XIAN, G., COULSTON, J., HEROLD, N., WICKHAM, J. & MEGOWN, K. 2015. Completion of the 2011 National Land Cover Database for the conterminous United States–representing a decade of land cover change information. *Photogrammetric Engineering & Remote Sensing,* 81**,** 345-354.

HOU, Y., ZHANG, M., MENG, Z., LIU, S., SUN, P. & YANG, T. 2018. Assessing the Impact of Forest Change and Climate Variability on Dry Season Runoff by an Improved Single Watershed Approach: A Comparative Study in Two Large Watersheds, China. *Forests,* 9**,** 46.

HUANG, C., CHEN, Y. & WU, J. 2014a. DEM-based modification of pixel-swapping algorithm for enhancing floodplain inundation mapping. *International Journal of Remote Sensing,* 35**,** 365-381.

HUANG, C., CHEN, Y. & WU, J. 2014b. Mapping spatio-temporal flood inundation dynamics at large river basin scale using time-series flow data and MODIS imagery. *International Journal of Applied Earth Observation and Geoinformation,* 26**,** 350-362.

HWANG, T., BAND, L. E., VOSE, J. M. & TAGUE, C. 2012. Ecosystem processes at the watershed scale: Hydrologic vegetation gradient as an indicator for lateral hydrologic connectivity of headwater catchments. *Water Resources Research,* 48.

HYANDYE, C. & MARTZ, L. W. 2017. A Markovian and cellular automata land-use change predictive model of the Usangu Catchment. *International Journal of Remote Sensing,* 38**,** 64-81.

IIZUMI, T., LUO, J.-J., CHALLINOR, A. J., SAKURAI, G., YOKOZAWA, M., SAKUMA, H., BROWN, M. E. & YAMAGATA, T. 2014. Impacts of El

Niño Southern Oscillation on the global yields of major crops. *Nature communications,* 5**,** 3712.
IPCC 2014. *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]*, Geneva, Switzerland, IPCC.
JENSEN, J. R. 2005. *Introductory digital image processing: A remote sensing approach.,* Upper Saddle River, NJ, Prentice Hall.
JENSEN, J. R. & COWEN, D. C. (eds.) 2011. *Remote Sensing of Urban/Suburban Infrastructure and Socio-Economic Attributes,* Chichester, United Kingdom: John Wiley & Sons, Ltd. .
KAMUSOKO, C., OONO, K., NAKAZAWA, A., WADA, Y., NAKADA, R., HOSOKAWA, T., TOMIMURA, S., FURUYA, T., IWATA, A. & MORIIKE, H. 2011. Spatial simulation modelling of future forest cover change scenarios in Luangprabang province, Lao PDR. *Forests,* 2**,** 707-729.
KAUFMAN, Y. J. & TANRE, D. 1992. Atmospherically resistant vegetation index (ARVI) for EOS-MODIS. *IEEE transactions on Geoscience and Remote Sensing,* 30**,** 261-270.
KIDSTON, J., SCAIFE, A. A., HARDIMAN, S. C., MITCHELL, D. M., BUTCHART, N., BALDWIN, M. P. & GRAY, L. J. 2015. Stratospheric influence on tropospheric jet streams, storm tracks and surface weather. *Nature Geoscience,* 8**,** 433.
KIM, S. B., TSANG, L., JOHNSON, J. T., HUANG, S., VAN ZYL, J. J. & NJOKU, E. G. 2012. Soil moisture retrieval using time-series radar observations over bare surfaces. *IEEE Transactions on Geoscience and Remote Sensing,* 50**,** 1853-1863.
KIRCHHOEFER, M., SCHUMACHER, J., ADLER, P. & KÄNDLER, G. 2017. Considerations towards a novel approach for integrating angle-count sampling data in remote sensing based forest inventories. *Forests,* 8**,** 239.
KISSINGER, G., HEROLD, M. & DE SY, V. 2012. *Drivers of deforestation and forest degradation: a synthesis report for REDD+ policymakers,* Vancouver Canada, Lexeme Consulting.
L'HEUREUX, M. L., TAKAHASHI, K., WATKINS, A. B., BARNSTON, A. G., BECKER, E. J., DI LIBERTO, T. E., GAMBLE, F., GOTTSCHALCK, J., HALPERT, M. S. & HUANG, B. 2017. Observing and predicting the 2015/16 El Niño. *Bulletin of the American Meteorological Society,* 98**,** 1363-1382.
LAUSCH, A., BORG, E., BUMBERGER, J., DIETRICH, P., HEURICH, M., HUTH, A., JUNG, A., KLENKE, R., KNAPP, S. & MOLLENHAUER, H. 2018. Understanding forest health with remote sensing, part III: requirements for a scalable multi-source forest health monitoring network based on data science approaches. *Remote Sensing,* 10**,** 1120.
LI, W., QIN, Y., SUN, Y., HUANG, H., LING, F., TIAN, L. & DING, Y. 2016. Estimating the relationship between dam water level and surface water area for the Danjiangkou Reservoir using Landsat remote sensing images. *Remote sensing letters,* 7**,** 121-130.
LILLESAETER, O. 1982. Spectral reflectance of partly transmitting leaves: laboratory measurements and mathematical modeling. *Remote Sens. Environ.,* 12**,** 247-254.

LILLESAND, T., KIEFER, R. W. & CHIPMAN, J. 2014. *Remote sensing and image interpretation,* New Jersey, John Wiley & Sons.
LIN, M., HOROWITZ, L. W., OLTMANS, S. J., FIORE, A. M. & FAN, S. 2014. Tropospheric ozone trends at Mauna Loa Observatory tied to decadal climate variability. *Nature Geoscience,* 7**,** 136.
LIPING, C., YUJUN, S. & SAEED, S. 2018. Monitoring and predicting land use and land cover changes using remote sensing and GIS techniques—A case study of a hilly area, Jiangle, China. *PloS one,* 13**,** e0200493.
MALLUPATTU, P. K. & SREENIVASULA REDDY, J. R. 2013. Analysis of land use/land cover changes using remote sensing data and GIS at an Urban Area, Tirupati, India. *The Scientific World Journal,* 2013.
MARTÍNEZ-VILALTA, J. & LLORET, F. 2016. Drought-induced vegetation shifts in terrestrial ecosystems: the key role of regeneration dynamics. *Global and Planetary Change,* 144**,** 94-108.
MCFEETERS, S. K. 1996. The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features. *International journal of remote sensing,* 17**,** 1425-1432.
MCFEETERS, S. K. 2013. Using the normalized difference water index (NDWI) within a geographic information system to detect swimming pools for mosquito abatement: A practical approach. *Remote Sensing,* 5**,** 3544-3561.
MEMON, A. A., MUHAMMAD, S., RAHMAN, S. & HAQ, M. 2015. Flood monitoring and damage assessment using water indices: A case study of Pakistan flood-2012. *The Egyptian Journal of Remote Sensing and Space Science,* 18**,** 99-106.
MISBARI, S. & HASHIM, M. 2016. Change detection of submerged seagrass biomass in shallow coastal water. *Remote Sensing,* 8**,** 200.
MUSA, S. I., HASHIM, M. & REBA, M. N. M. 2017a. A review of geospatial-based urban growth models and modelling initiatives. *Geocarto International,* 32**,** 813-833.
MUSA, S. I., HASHIM, M. & REBA, M. N. M. 2017b. Urban Growth Assessment and its Impact on Deforestation in Bauchi Metropolis, Nigeria using Remote Sensing and GIS Techniques. *ARPN Journal of Engineering and Applied Sciences,* 12**,** 1907-1914.
MUSA, S. I., HASHIM, M. & REBA, M. N. M. 2018. Geospatial modelling of urban growth for sustainable development in the Niger Delta Region, Nigeria. *International Journal of Remote Sensing***,** 1-29.
NGUYEN, T. 2015. Optimal Ground Control Points for Geometric Correction Using Genetic Algorithm with Global Accuracy. *European Journal of Remote Sensing,* 48**,** 101-120.
OTUKEI, J. R. & BLASCHKE, T. 2010. Land cover change assessment using decision trees, support vector machines and maximum likelihood classification algorithms. *International Journal of Applied Earth Observation and Geoinformation,* 12**,** S27-S31.
PATRICOLA, C. M., SARAVANAN, R. & CHANG, P. 2014. The impact of the El Niño–Southern Oscillation and Atlantic meridional mode on seasonal Atlantic tropical cyclone activity. *Journal of Climate,* 27**,** 5311-5328.
PELLIZZARI, E., CAMARERO, J. J., GAZOL, A., SANGÜESA-BARREDA, G. & CARRER, M. 2016. Wood anatomy and carbon-isotope discrimination support long-term hydraulic deterioration as a major cause of drought-induced dieback. *Global change biology,* 22**,** 2125-2137.

PETERS, T. & RICHTER, M. 2016. The atmospheric circulation. *Tropical forestry handbook*, 303-331.
PFANZAGL, J. 1994. *Parametric statistical theory*, Berlin, DE, Walter de Gruyter.
POWER, S., DELAGE, F., CHUNG, C., KOCIUBA, G. & KEAY, K. 2013. Robust twenty-first-century projections of El Niño and related precipitation variability. *Nature*, 502, 541.
PREETHI, B., SABIN, T., ADEDOYIN, J. & ASHOK, K. 2015. Impacts of the ENSO Modoki and other tropical Indo-Pacific climate-drivers on African rainfall. *Scientific reports*, 5, 16653.
QIANG, Y. & LAM, N. S. 2015. Modeling land use and land cover changes in a vulnerable coastal region using artificial neural networks and cellular automata. *Environmental monitoring and assessment*, 187, 57.
RAMIREZ, K. S., KNIGHT, C. G., DE HOLLANDER, M., BREARLEY, F. Q., CONSTANTINIDES, B., COTTON, A., CREER, S., CROWTHER, T. W., DAVISON, J. & DELGADO-BAQUERIZO, M. 2018. Detecting macroecological patterns in bacterial communities across independent studies of global soils. *Nature microbiology*, 3, 189.
RASMUSSON, E. M. & CARPENTER, T. H. 1982. Variations in tropical sea surface temperature and surface wind fields associated with the Southern Oscillation/El Niño. *Monthly Weather Review*, 110, 354-384.
RAWAT, J. & KUMAR, M. 2015. Monitoring land use/cover change using remote sensing and GIS techniques: A case study of Hawalbagh block, district Almora, Uttarakhand, India. *The Egyptian Journal of Remote Sensing and Space Science*, 18, 77-84.
REED, M. & STRINGER, L. C. 2015. *Climate change and desertification: Anticipating, assessing & adapting to future change in drylands. Impulse Report for the 3rd UNCCD Scientific Conference on: "Combating desertification/land degradation and drought for poverty reduction and sustainable development: the contribution of science, technology, traditional knowledge and practice". 9-12 March 2015, Cancun, Mexico*, Montpellier, Agropolis International.
RICHARDS, J. A. & JIA, X. 1999. *Remote sensing digital image analysis*, Berlin, Springer.
ROPELEWSKI, C. F. & HALPERT, M. S. 1987. Global and regional scale precipitation patterns associated with the El Niño/Southern Oscillation. *Monthly weather review*, 115, 1606-1626.
ROZAS, V. & GARCÍA-GONZÁLEZ, I. 2012. Too wet for oaks? Inter-tree competition and recent persistent wetness predispose oaks to rainfall-induced dieback in Atlantic rainy forest. *Global and Planetary Change*, 94, 62-71.
SALINGER, M. J. 2005. Climate variability and change: past, present and future—an overview. *Increasing climate variability and change.* Springer.
SALITE, D. 2019. Explaining the uncertainty: understanding small-scale farmers' cultural beliefs and reasoning of drought causes in Gaza Province, Southern Mozambique. *Agriculture and Human Values*, 1-15.
SARACHIK, E. S. & CANE, M. A. 2010. *The El Nino-southern oscillation phenomenon*, Cambridge University Press.
SEBER, G. A. & LEE, A. J. 2012. *Linear regression analysis*, New Jersey, John Wiley & Sons.
SONG, C., WOODCOCK, C. E., SETO, K. C., LENNEY, M. P. & MACOMBER, S. A. 2001. Classification and change detection using Landsat TM data: when

and how to correct atmospheric effects? *Remote sensing of Environment,* 75**,** 230-244.
SOTI, V., TRAN, A., BAILLY, J. S., PUECH, C., SEEN, D. L. & BÉGUÉ, A. 2009. Assessing optical earth observation systems for mapping and monitoring temporary ponds in arid areas. *International Journal of Applied Earth Observation and Geoinformation,* 11**,** 344-351.
SRIVASTAVA, P. K., PANDEY, P. C., KUMAR, P., RAGHUBANSHI, A. S. & HAN, D. 2016. *Geospatial Technology for Water Resource Applications,* Boca Raton, Florida, CRC Press.
STANCALIE, G. & SERBAN, F. 2014. Agricultural Drought Monitoring Using Satellite-Based Products in Romania. *ICTRS 2014***,** 100.
STEPHENSON, N. L., DAS, A. J., AMPERSEE, N. J., CAHILL, K. G., CAPRIO, A. C., SANDERS, J. E. & WILLIAMS, A. P. 2018. Patterns and correlates of giant sequoia foliage dieback during California's 2012–2016 hotter drought. *Forest Ecology and Management,* 419**,** 268-278.
SULTANA, A. & KUMAR, A. 2012. Optimal siting and size of bioenergy facilities using geographic information system. *Applied Energy,* 94**,** 192-201.
TAN, M. 2014. Circulation effect: response of precipitation δ 18 O to the ENSO cycle in monsoon regions of China. *Climate Dynamics,* 42**,** 1067-1077.
TEWKESBURY, A. P., COMBER, A. J., TATE, N. J., LAMB, A. & FISHER, P. F. 2015. A critical synthesis of remotely sensed optical image change detection techniques. *Remote Sensing of Environment,* 160**,** 1-14.
TOWNROE, S. & CALLAGHAN, A. 2014. British Container Breeding Mosquitoes: The Impact of Urbanisation and Climate Change on Community Composition and Phenology. *PLOS ONE,* 9**,** 1-7.
TRENBERTH, K. E., DAI, A., VAN DER SCHRIER, G., JONES, P. D., BARICHIVICH, J., BRIFFA, K. R. & SHEFFIELD, J. 2014. Global warming and changes in drought. *Nature Climate Change,* 4**,** 17.
TUCKER, C. J. 1980. Remote sensing of leaf water content in the near infrared. *Remote Sensing of Environment,* 10**,** 23-32.
UNITED NATIONS 2015. *Resolution adopted by the General Assembly on 25 September 2015,* New York, United Nations.
VENTER, O., SANDERSON, E. W., MAGRACH, A., ALLAN, J. R., BEHER, J., JONES, K. R., POSSINGHAM, H. P., LAURANCE, W. F., WOOD, P. & FEKETE, B. M. 2016. Sixteen years of change in the global terrestrial human footprint and implications for biodiversity conservation. *Nature Communications,* 7**,** 12558.
WANG, C. & FIEDLER, P. C. 2006. ENSO variability and the eastern tropical Pacific: A review. *Progress in Oceanography,* 69**,** 239-266.
WEI, Y. D. & YE, X. 2014. Urbanization, urban land expansion and environmental change in China. *Stochastic Environmental Research and Risk Assessment,* 28**,** 757-765.
WEN, C., KUMAR, A., XUE, Y. & MCPHADEN, M. 2014. Changes in tropical Pacific thermocline depth and their relationship to ENSO after 1999. *Journal of Climate,* 27**,** 7230-7249.
WORK JR, E. A. & GILMER, D. S. 1976. Utilization of satellite data for inventorying prairie ponds and lakes. *Ann Arbor,* 1001**,** 48107.
WU, J., ZHANG, J., LÜ, A. & ZHOU, L. 2012. An exploratory analysis of spectral indices to estimate vegetation water content using sensitivity function. *Remote sensing letters,* 3**,** 161-169.

XIE, H., LUO, X., XU, X., TONG, X., JIN, Y., PAN, H. & ZHOU, B. 2014. New hyperspectral difference water index for the extraction of urban water bodies by the use of airborne hyperspectral images. *Journal of Applied Remote Sensing,* 8**,** 085098.

XU, H. 2006. Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery. *International journal of remote sensing,* 27**,** 3025-3033.

YAGOUB, M. & AL BIZREH, A. A. 2014. Prediction of land cover change using Markov and cellular automata models: case of Al-Ain, UAE, 1992-2030. *Journal of the Indian Society of Remote Sensing,* 42**,** 665-671.

YAO, F., WANG, C., DONG, D., LUO, J., SHEN, Z. & YANG, K. 2015. High-resolution mapping of urban surface water using ZY-3 multi-spectral imagery. *Remote Sensing,* 7**,** 12336-12355.

YOUNG, D. J., STEVENS, J. T., EARLES, J. M., MOORE, J., ELLIS, A., JIRKA, A. L. & LATIMER, A. M. 2017. Long-term climate and competition explain forest mortality patterns under extreme drought. *Ecology Letters,* 20**,** 78-86.

ZAROUG, M. A., ELTAHIR, E. A. & GIORGI, F. 2014. Droughts and floods over the upper catchment of the Blue Nile and their connections to the timing of El Niño and La Niña events. *Hydrology and Earth System Sciences,* 18**,** 1239-1249.

ZHANG, N., HONG, Y., QIN, Q. & LIU, L. 2013. VSDI: a visible and shortwave infrared drought index for monitoring soil and vegetation moisture based on optical remote sensing. *International journal of remote sensing,* 34**,** 4585-4609.