Towards sustainability: Overcoming the physical barriers to urban green spaces in Kumasi, Ghana

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Abstract

Conserving green spaces (parks, gardens, forest) in the physical landscape of cities is an action that has been identified as contributing to the sustainability of cities. However, to be able to conserve such spaces, some barriers need to be overcome, and this has not received much attention. This paper therefore provides measures to overcome the 'physical' barriers to urban green spaces in order to enhance the sustainability of such spaces in Ghana, using Kumasi as a case study. A qualitative research approach, 30 in-depth interviews, ten focus group discussions, archival data, and numerous observation sessions were utilized in the study. Kumasi city authorities, allied bodies on green spaces, opinion leaders, and residents of Kumasi constituted the study's target population. It was discovered that conflicting ownership rights, encroachment, and poor maintenance are major physical barriers hampering the development of urban green spaces. To enhance the sustainability of urban green spaces, the study recommends that there should be the creation of additional parks and gardens, conversion of brownfield sites into green spaces, incorporation of quantitative standards into the provision of green spaces, and institutionalization of an award scheme on green spaces.

Keywords: sustainability, green spaces, physical barriers, Kumasi, Ghana

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Introduction

Globally, the world has witnessed several initiatives towards achieving a sustainable world, with the latest one adopted on 25 September 2015 in New York, when leaders of over 190 countries signed the 2030 Agenda for Sustainable Development. Popularly known as Sustainable Development Goals (SDGs), this new initiative has set out 17 goals to cover issues such as climate change, poverty, health and well-being, water and sanitation, inequalities, and sustainable cities (United Nations, 2015). The SDGs are an extension of the Millennium Development Goals (MDGs), which were adopted in 2000 by the UN to address extreme poverty and related matters such as hunger, disease, lack of shelter, and environmental problems by 2015.

Ghana was a signatory to the MDGs, and for the past 15 years (2000–2015) has made a number of efforts to achieve the eight main goals of the MDGs. The country's final progress report on the MDGs in 2015 revealed that four of the eight MDGs were largely achieved. The achieved goals were as follows: eradication of extreme poverty (Goal 1); universal primary education (Goal 2); reduction of child mortality (Goal 4); and global partnership for development (Goal 8). Among the remaining four goals that were not achieved by Ghana was Goal 7: ensuring environmental sustainability (National Development Planning Commission [NDPC], 2015). Statistics show that between 1990 and 2010, Ghana lost about 2.51 million ha of forest cover and related green vegetation—including urban green spaces, which are basically open spaces in urban areas primarily covered by green vegetation and available for human usage. Examples of these green spaces include parks, gardens, trees, forest, and farmlands. According to NDPC (2015), Ghana's inability to achieve environmental sustainability over the past 15 years was largely due to the country's failure to devote much attention to devising sustainable measures to preserve its environmental resources, including green spaces.

Among the current SDGs, Goal 11 in particular focuses on sustainable cities and communities and emphasizes the creation, preservation, and integration of public green spaces into communities' physical landscape to enhance the quality of life. However, with Ghana's previous record of being unable to achieve environmental sustainability within the framework of the MDGs, the question now is this: Will Ghana be able to sustain its natural vegetation (including urban green spaces) this time round under the SDGs? Studies on urban green spaces in Ghana indicate that these spaces are under threat, with many such spaces, supposedly reserved for parks, gardens, forests, and nature reserves, being continually encroached on for diverse human activities. For example, a study in Sekondi Takoradi by Stemn and Agyapong (2014) found about 3,437 ha of green space lands lost to residential, commercial, and industrials activities. Similarly, a study by Mensah (2014a) on Kumasi, Ghana's second city and once the garden city of West Africa, revealed that the city has now lost its garden city status owing to many of the green spaces having been destroyed for commercial and residential purposes.

Notwithstanding the loss of these green spaces in Ghana, existing studies have failed to touch on how such spaces can be sustained in the physical landscape of cities amidst the development pressures affecting our cities. It was therefore to fill this knowledge gap that this study was undertaken. The main objective of this paper is to recommend measures to overcome the physical barriers to urban green spaces in order to enhance the sustainability of such spaces in Ghana, using Kumasi as a case study. Physical barriers in this context mean the inability to have direct contact with green spaces. The findings of this paper, among other aspects, contribute ideas to support Ghana's efforts to protect its natural vegetation under the SDGs (Goal 11), which the country failed to achieve when the MGDs were in operation. It also provides policy makers and city authorities with varied strategies which they can rely on to conserve green spaces—especially in Africa and Ghana, where such spaces are under threat.

Environmental sustainability and urban green spaces

Environmental sustainability as captured in the broad concept of sustainable development is associated with preservation of the natural environment. Sutton (2004) defines it as the ability to maintain elements (such as biodiversity, climate, and air) valued in the physical environment (natural and biological environments). Morelli (2011: 6), looking at environmental sustainability from a broader perspective, described it as follows:

> *…a condition of balance, resilience, and interconnectedness that allows human society to satisfy its needs while neither exceeding the capacity of its supporting ecosystems to continue to regenerate the services necessary to meet those needs nor by our actions diminishing biological diversity.*

Maintenance of the natural environment serves as a central theme that dominates discussions on environmental sustainability. This has led to a debate on what exactly should be maintained in the natural environment. According to Sutton (2004), aspects of the natural environment that need to be maintained (sustained) include the natural beauty of the environment, high-quality urban environments, ecosystem services (nutrient cycling, the water cycle, natural water), and the user value flowing from physical resources (e.g. minerals, energy, renewable resources, water purification, climate moderation, soil protection). Siraj-Blatchford et al. (2010) noted that depleted natural resources, increased greenhouse gas emissions, overflowing landfills, loss of biodiversity, and polluted waterways are major environmental problems that should be addressed so that the natural state of the natural environment can be maintained.

Having different forms of green spaces, such as parks, gardens, forests, woodlands, and wetlands, provides a range of benefits, such as conserving biodiversity, ameliorating local climate, improving air quality, controlling soil erosion, providing venues for recreation activities, and enhancing eco-tourism (Cilliers et al., 2013). The availability of green spaces has been observed to help maintain large portions of the natural environment (Fam et al., 2008), indicating a strong linkage between green spaces and environmental sustainability. In view of this, Jim (2004) stressed two main approaches that could be pursued to enhance the sustainability of green spaces. First is maintaining all existing green spaces (parks, gardens, forest, farmlands, wetlands, etc.), and second is creating new green sites to augment the existing ones. The approach of maintaining existing green spaces involves getting rid of the various physical barriers that prevent people from having direct access to these spaces. The literature on green spaces (Djibril et al., 2012; Addo-Fordwuor, 2014; Mensah, 2014b) shows that physical barriers such as encroachment and poor maintenance of green spaces not only deny individuals the opportunity to use such spaces to satisfy their recreational needs, but also cause depletion of large tracts of green space lands. For example, in cities such as Nairobi (Kenya), Kumasi (Ghana), and Abidjan (Cote D'lvoire), many green space lands are either not in existence or in poor condition due to these physical barriers (Mensah, 2014b). The outcome of the above two approaches is conservation of natural vegetation to provide numerous ecosystem services to support sustainable development (Cho et al., 2008; Dobbs et al., 2011; Escobedo et al., 2011; Niemela et al., 2010; Cilliers et al., 2013). Such ecosystem services include regulating microclimates, habitat provision, carbon sequestration and storage, gas cycles, rain water absorption, and control of environmental pollution (air, water, and noise) (Niemela et al., 2010).

All these conservation practices are intended to provide healthy environments to enhance the well-being of individuals. This falls under the broad scope of governance, which the OECD conceptualized as using political authority and exercising control over the management of society's resources to achieve social and economic development (Gisselquist, 2012). In urban areas, in managing urban development and its associated resources (natural and man-made resources), there has been a paradigm shift from the traditional system of 'government', which emphasized hierarchy and clear demarcation lines between the state and society, to a new system of 'governance', whereby the organizational set-up encourages networks and overlapping roles of the state and different societal actors (Kjaer, 2009). Ansell and Gash (2008) and Innes and Booher (2004) called this kind of governance 'collaborative governance', whereby one or more public agencies directly engage non-state stakeholders in a collective decision-making process to manage public programmes and assets. The features of collaborative governance include dialogue, consensus building, mutual understanding, facilitative leadership, regulation of power, institutional design, and community participation.

The study area

This study was undertaken in Kumasi, the second city of Ghana. The rationale for selecting Kumasi was that it represents most of the issues facing urban green spaces in Ghana and Africa, such as rapid depletion of green spaces and the unsustainable nature of these spaces (Mensah, 2014c). The city was built on the garden city model, which supports the incorporation of many green spaces into cities' physical landscapes (Adarkwa & Owusu-Akyaw, 2001; Quagraine, 2011). The 1945 city plan of Kumasi, the Kumasi Planning Scheme between 1963 and 1988, and other planning schemes that underlie the physical development of Kumasi dedicated a substantial part of the city's landmass to green spaces (Quagraine, 2011). In the 1960s, the city gained the accolade 'the garden city of West Africa', mainly because of the presence of many well-planned green spaces interspersed with physical land developments (Geurts, 2009; Quagraine, 2011). During that period, over 60% of the land area of the city was covered with green spaces; but since 2005, concerns have been raised about the city losing most of its green spaces (Tontoh, 2011).

The city has a total population of just over 2 million, making it the second-largest city in Ghana (Ghana Statistical Service, 2012). It falls within the moist, semi-deciduous vegetation zone of Ghana, which has favourable soil conditions that support farming and green vegetation. Five communities (Patasi, Danyame, Ahodwo, Nhyiaso, and Amakom) were selected as cases for the study (Figure 1). This was done in consultation with the Department of Parks and Gardens, the official body in charge of green spaces in Kumasi. These areas were selected based on the roles they play in green space management. In addition, the green spaces in the central business district (CBD) and other vantage points were used as another case.

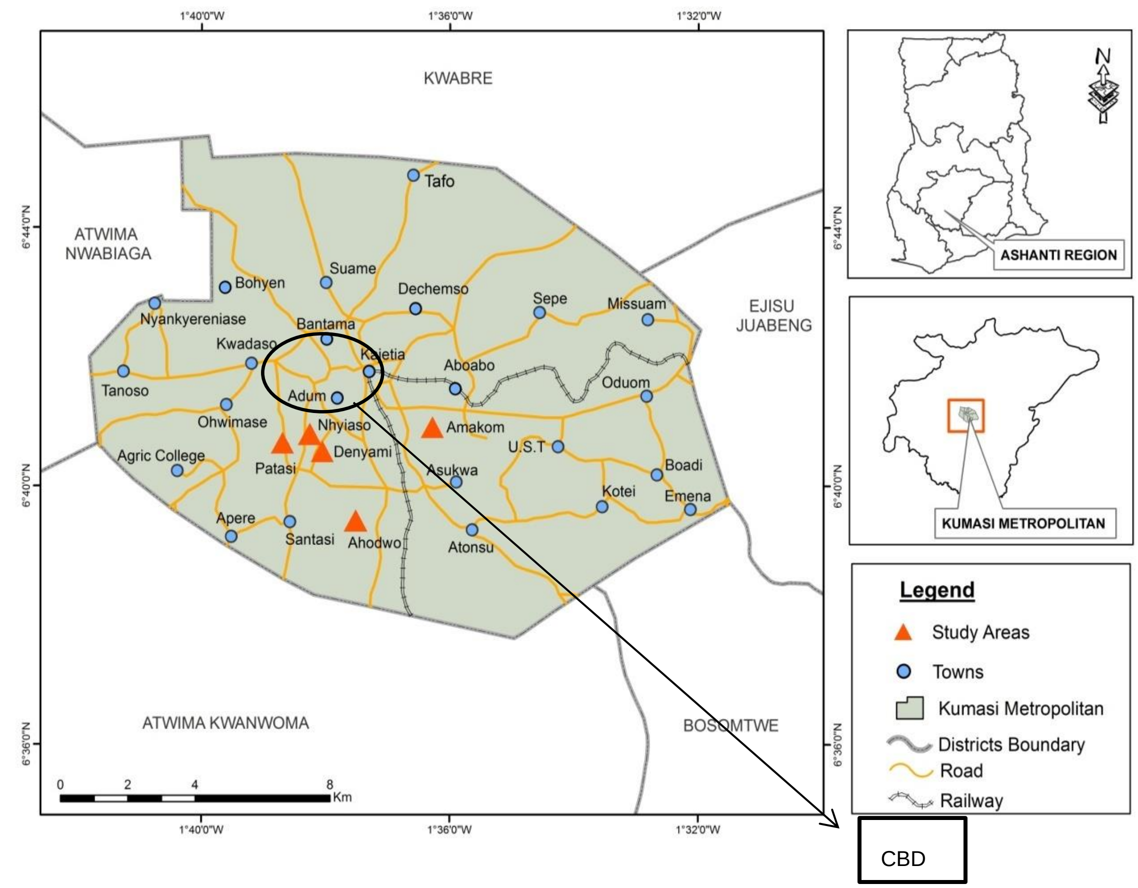

Figure 1: Map of Kumasi showing selected sites for the study

Source: Department of Geography and Regional Planning, University of Cape Coast (2013)

CBD: Central Business District

Approach and methodology

A combination of descriptive and explanatory case study approaches was used in the study. This enabled the study to describe and explain the physical barriers affecting the development of green spaces and suggested possible solutions to address the problem (Yin, 2003; Hancock & Algozzine, 2006). The study was purely qualitative, and this was because it demanded an in-depth understanding of the deteriorating condition of green spaces in order for tailored measures to be provided to enhance the sustainability of such spaces in Kumasi. In accordance with the qualitative nature of the study, and as recommended by Yin (2003), a blend of qualitative methods such as in-depth interviews, focus group discussions, personal observations, and archival data was relied upon. Four categories of people constituted the study's target population. These were the residents of the selected five communities, city authorities, opinion leaders, and officials of allied bodies on green spaces. The selection of the respondents was based on a theoretical or purposive sampling technique (Mills et al., 2010). Respondents were selected based on the roles they play in regard to green spaces. The city authorities serve as policy makers on green spaces; the allied bodies on green spaces manage these spaces; and opinion leaders and residents serve as users of the green spaces. In all, 30 in-depth interviews were conducted with key informants, who included opinion leaders, city authorities, and representatives of allied bodies on green spaces. In addition, ten focus group discussions were undertaken in the selected communities. In each of the five communities, two focus group discussions were conducted, one for the youth (18–45 years) and one for the elderly (46 years and over). This was to get the views and experiences of both the young and old on green spaces in order to draw informed conclusions. Each of the focus groups had participant numbers ranging from seven to ten.

Data from both the in-depth interviews and focus group discussions were analysed using the theoretical proposition strategy recommend by Yin (2003), which requires interview data to be analysed under key themes or topics derived from a study's objective. In doing so, the data obtained, which were primarily audio tape-recorded, were first transcribed, and appropriate codes were created for the transcribed data to identify the major issues that emerged. Afterwards, ideal categories or themes were identified, and the data obtained were placed under these themes. Data under the themes were examined or pursued several times to gain a better understanding of their content. Finally, the general trends or patterns of the data were identified and used to support the discussion of the paper. All these were performed manually. In addition to the data from in-depth interviews and focus group discussions, archival data in the form of planning schemes or layouts of the selected communities were utilized, and numerous personal observation sessions were also undertaken on various green spaces to gain first-hand information about the state of those spaces.

Physical barriers to green spaces in Kumasi

Three broad factors were found from the primary data obtained from the study area to be physical barriers to green spaces in Kumasi: conflicting ownership rights on green spaces, encroachment, and poor maintenance. The conflicting ownership rights on green spaces were found to arise among the Lands Commission, the Kumasi Metropolitan Assembly (KMA), and the traditional authorities (chiefs) of the area. These three bodies traced their sources of power over green spaces to different legislative provisions (Table 1). These provisions were found to have influenced each of the three bodies to believe that it has the main responsibilities for controlling urban green spaces in Kumasi.

Table 1: Conflict of power over green spaces

Body/Institution	Claim of power	Source of power
Lands Commission	Power over ownership and management of green spaces	1992 Constitution of Ghana (Article 258) Lands Commission Law of 1994 (Act 483)
Kumasi Metropolitan Assembly (KMA)	Power over management of green spaces	Local Government Law of 1993 (Act 462)
Traditional Authorities (Chiefs)	Power over ownership and management of green spaces	1992 Constitution of Ghana (Article 267)

Source: Fieldwork (2013)

Their positions became clearer when the representatives from these bodies made statements to express their organization's views on the management and ownership of green spaces in Kumasi. For example, representatives of the traditional authorities (chiefs) and KMA remarked as follows:

> *The traditional authorities (chiefs) have major powers over green spaces in Kumasi. The majority of the green spaces are part of 'stool lands' [lands owned by the traditional ruler of Kumasi and held in trust by various sub-chiefs for the people of Kumasi], and the constitution of Ghana (Article 267) gives us authority over the ownership of such lands. No activity can be undertaken on stool lands without our prior consents and approval. (Chief, Community A)*

> *All the green spaces in Kumasi fall under the control of the KMA. The KMA is the local planning authority of Kumasi, and it has the power mandated by law to control all forms of developments in Kumasi. The Local Government Law of 1993 (Act 462) gives us the political and administrative powers over all physical developments of Kumasi, which matters on green spaces fall under. (Official of Development Planning Unit of KMA)*

The different views held by the above bodies on the ownership and management of green spaces makes it difficult for them to come together as a unifying body to manage green spaces. Although the 1992 Constitution of Ghana (Article 258) and the Lands Commission Law of 1994 (Act 483) give powers to the Lands Commission to manage public lands on behalf of the Government of Ghana, the study found that there is no clause in the regulations that mandates the Lands Commission to register green space lands as government property and manage them accordingly. A senior official from the Lands Commission remarked as follows:

> *The laws [Article 258 and Lands Commission Law, Act 483] give us the authority to manage public lands (including green spaces), but there is no quotation in the laws which allows us to register green space lands as public lands. This has created confusion about our power over the management of green spaces. (Official of Lands Commission)*

This serves as a major obstacle to the Lands Commission. It prevents them from having absolute control over the management of green spaces, since they do not have in their custody registered land documents on green spaces to give them undisputed control over such lands. Furthermore, the constitutional provision in Article 267 of Ghana's Constitution means the traditional authorities in Kumasi have maximum control over all 'stool lands', which constitute the greater portion of the landmass of Kumasi (about 60%) (KMA, 2010). By implication, this provision gives power to the chiefs in Kumasi to take possession of green spaces, and this conflicts with the mandates of the Lands Commission. However, how the green spaces on stool lands should be preserved and managed, and by whom, remains unclear, since Article 267 of Ghana's Constitution is silent on these matters. Compounding the problem is the KMA, which by the Local Government Law of 1993 (Act 462) also has power to oversee the overall management and planning of Kumasi, including its green spaces. What is critical is that, like the Lands Commission, both the KMA and the traditional authorities were found not to have the right to register green space lands as property that belongs to them. Representatives from these three bodies confirmed this problem and expressed great concerns about it. Technically, this situation makes green space land 'no man's land' in Kumasi, since no one has legal registered documents covering these lands. This has resulted in little or no attention being given to green spaces in the city.

Encroachment on green spaces served as another physical barrier to the sustainability of green spaces in Kumasi. A cross-examination of the layouts or planning schemes of the study communities found places delineated on the layouts for green spaces, but on the ground they were found invaded by individuals for residential and commercial land uses. For instance, in communities such as Ahodwo, Nhyiaso, and Patasi, green spaces were found encroached on for residential and commercial land uses, with offenders left unpunished. Specific mention can be made of the 'Mango Down' area at Patasi Community, and along River Washy in Ahodwo Community where many green spaces have been encroached on for residential and commercial purposes. The widespread encroachment on green spaces was observed to be influenced by poor enforcement of development controls by the city authorities, resulting in the depletion of many green spaces. The outcome is few or limited availability of green spaces in Kumasi.

To provide further evidence to support the limited availability of green spaces, the per capita green space of the city was estimated. Globally, for a city to have enough green spaces for its dwellers, the World Health Organisation (WHO) recommends a minimum standard of 9 square metres (sq m) of green space per city dweller (Kuchelmeister, 1998; Sanesi & Chiarello, 2006; Fuady & Darjosanjoto, 2012). Using this standard as a guide, the per capita green space of Kumasi was estimated. There was scant information about the quantity of green spaces in the study area, so some deductions were made from the 2010 estimated total amount of open spaces in Kumasi, which was 2375.4 ha (Ministry of Lands and Natural Resources, 2010). This figure comprised many different spaces other than green spaces, so further enquiry was undertaken to address the matter. A study by Tontoh (2011) and data from the KMA confirmed that green spaces occupy about 40% of the total amount of open spaces in the area. Taking into account the latest population census figures of the total population of Kumasi (2,035,064) (Ghana Statistical Service, 2012), an estimated 4.7 sq m of green space per head was obtained (Figure 2).

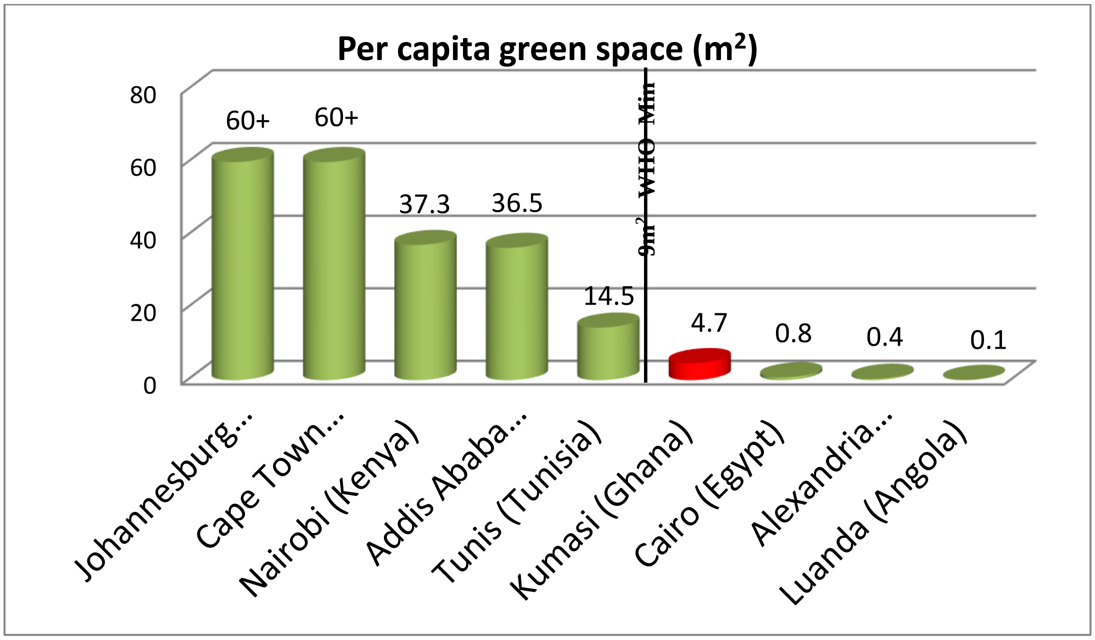

Figure 2: Green space per city dweller of Kumasi in the context of Africa

Source: Author's construct (2014)

The above estimations showed that the per capita green space in Kumasi (4.7 sq m) was far below the minimum green space standard recommended by the WHO (9 sq m). In the context of Africa, the per capita green space of Kumasi was far below that of Johannesburg (South Africa), Nairobi (Kenya), and Addis Ababa (Ethiopia) (Lange & McNamara, 2011). The above analysis shows that Kumasi requires more than 4 sq m of extra green space per capita to meet the WHO's minimum standard.

Aside from encroachment on green spaces and the associated limited availability of such spaces, poor maintenance of facilities was another physical barrier in Kumasi. Interviews with the Kumasi city authorities revealed alienation or abandonment of some parks for several years, without maintenance works being undertaken on them. The Kumasi Children's Park, Abbey's Park, and Fante Newtown Park were among the major parks that were found in such a situation. An official of the Department of Parks and Gardens commented extensively on the broken-down facilities at many green spaces, and the poorly maintained grasses, lawns, trees, and shrubs in the CBD and along the principal streets of Kumasi.

Responses by selected opinion leaders provided much evidence of widespread poor maintenance of green spaces in the city. For example:

> *The Kumasi Children's Park has been abandoned for many years without receiving any maintenance work. None of the facilities on it is functioning. Its pavilion has been turned into a church premise for some churches, while its library structure is used as a place of abode for the homeless and social deviants. (Unit Committee member, Amakom Community).*

> *Abbey's Park is not functioning properly because of poor maintenance. Due to poor maintenance, it has lost all the grasses and trees that made the place lively. Similarly, poor maintenance has caused Adehyeman Gardens to lose many facilities and its green environment. (Opinion leader, Patasi Community)*

Lack of financial commitments towards the maintenance of green spaces was the substantive factor behind this problem. It was found that the Kumasi city authorities do not have stable funds allocated for the maintenance of green spaces owing to financial constraints. These revelations about poor maintenance confirmed the findings of Deneva et al. (2008) and the 2012 Global Garden Report, which pointed out poor maintenance as a devastating problem that is undermining the growth of green spaces in cities worldwide (Husqvarna Group, 2012). Apart from financial hardships, poor collaboration among allied government bodies on green spaces and private organizations, and a culture of poor maintenance were also found to hinder the maintenance of such spaces. In Kumasi, it was observed that frequent maintenance of facilities in green spaces is not a habit shown by the city authorities and other allied bodies on green spaces. Even if the means are there, facilities in green spaces are often allowed to break down for a long period of time before actions are undertaken to repair the worn-out facilities. This problem has rendered the few parks available in Kumasi unattractive for the residents to use for their recreational activities (Figure 3).

Kumasi Children's Park Abbey's Park

Figure 3: Poor maintenance of selected green spaces in Kumasi

Source: Fieldwork (2013)

Overcoming the physical barriers to green spaces

In line with different factors discussed above that serve as the main physical barriers to green spaces, this section discusses strategies that can be adopted to overcome these physical barriers to enhance the sustainability of green spaces in Kumasi. Three broad strategies were found useful from the analyses of data collected from the field. These were enhancing the availability of green spaces, enhancing the maintenance of green spaces, and controlling the encroachment on green spaces.

Enhancing the availability of green spaces

Interviews with key informants and field observations revealed that creating additional green spaces, such as parks and gardens, to augment the existing ones is one particular strategy that could be pursued to increase the availability of green spaces in Kumasi. The remarks of some key informants on this strategy are listed in Table 2.

Table 2: Responses of key informants on creating additional parks

Agency/organisation	Response
Department of Parks and Gardens (DPG)	'Additional parks have to be created to make Kumasi greener. This is important because it will help the city get more parks to satisfy the recreational needs of the residents.' (Official, DPG)
Town and Country Planning Department (TCPD)	'More parks have to be created. Areas demarcated as parks on the layouts or planning schemes of various neighbourhoods have to be implemented.' (Official, TCPD)
Forest Service Division (FSD)	'To address the problem of limited green spaces in Kumasi, the city authorities have to resort to massive tree-planting exercises and the creation of more parks and gardens in the city.' (Official, FSD)
Department of Horticulture (KNUST)*	'Many parks have to be designed to enhance the beauty of Kumasi. Kumasi has lost most of its parks and gardens.' (Official, Department of Horticulture [KNUST])
Environmental Protection Agencies (EPA)	'Kumasi needs additional parks and gardens. Currently, the city has very few natural parks to serve the over 2 million human population of the city.' (Official, EPA)

*KNUST: Kwame Nkrumah University of Science and Technology.

Source: Fieldwork (2013)

A close examination of the planning schemes/layouts of the study communities (Amakom, Danyame, Nhyiaso, Ahodwi, and Patasi) found as many as eight areas delineated on the layouts as sites for the development of parks/gardens, but these remain undeveloped on the ground (Table 3). This was due to lack of funds and poor enforcement of these provisions by the city authorities.

Table 3: Sites demarcated on planning schemes for parks/gardens but not developed

Neighbourhood	Park/garden not developed	Location
Amakom	1	Around Kumasi Technical Institute
Danyame	1	Opposite New Orleans Hotel
Nhyiaso	1	Adjacent Golden Tulip Hotel
Patasi	5	Around the premises of Department of Parks and Gardens; opposite former micro-wave station; between blocks 'K' and 'I' at North Patasi; O. S. garden around 'block G' at South Patasi; 2 land areas at 'block J' at North Patasi.

Source: Fieldwork (2013)

A collaborative effort by the KMA, the allied agencies on green spaces, and the local people in developing these parks/gardens—as emphasized by the concept of collaborative governance (Healey, 2006)—can help in the realization of these projects. Such collaboration in Kumasi will offer a platform for joint discussions where shared ideas on developing the identified locations as green spaces can be tapped. It will also open avenues for the contribution of financial resources and technical expertise from various stakeholders and of 'local knowledge'—knowledge gained through practical experience in a given locality, especially from local people—to develop these green spaces to meet the needs of the residents of Kumasi. Furthermore, developing the proposed site for a new children's park at the Dakodjom Community can also help to improve the availability of green spaces in Kumasi. An inventory analysis of the proposed site by Taylor (2010) confirmed the suitability of this site for a children's park.

Another strategy found useful to enhance the availability of green spaces in Kumasi was the conversion of brownfield sites into green spaces. Brownfield sites are typically abandoned lands previously used for industrial, commercial, or other specific activities but are now available for redevelopment. Officials from the Departments of Parks and Gardens and from the Horticulture and Planning Departments of KNUST supported this strategy and indicated that this would help minimize how valuable lands of the city are always converted into commercial land uses without thinking about conserving the green vegetation. Observations from the study revealed that one particular brownfield site in Kumasi that could be used for a green space is the former race-course ground. This land, over the past decade, has been turned into an open market place where traders sell their items, but the area for some time now has been cleared and earmarked for redevelopment. Converting a substantial part of this land into green spaces will help increase the availability of green spaces in Kumasi, especially for surrounding communities such as Bantama, Adum, Suame, and the old military barracks (4BN). As stressed by De Sousa (2003, 2006), benefits such as conserving the ecological habitat, increasing recreational activities, and enhancing public health associated with the conversion of brownfield sites into green spaces can be derived from this strategy when implemented in Kumasi.

Incorporating quantitative standards into the provision of green spaces serves as another strategy that can increase the availability of green spaces in Kumasi. Content analysis of the available regulations on city management and the natural environment in Ghana—such as the Town and Country Planning Act of 1945 (Cap 84), Local Government Act of 1993 (Act 462), National Development Planning System Act of 1994 (Act 480), National Urban Policy and Environmental Protection Agency Act of 1994 (Act 490)—found no specific quantitative guidelines on the provision of green spaces. Elsewhere, quantitative standards on green spaces such as 2 ha of accessible green space per 1,000 population, 6.25–10.5 acres of green space per 1,000 residents, and green spaces per square metres have been incorporated into planning regulations and strictly adhered to (National Parks and Recreation Association, 2000; Handley et al., 2003). The quantitative standards serve as a benchmark to guide the provision of green spaces and inform planning decisions on green spaces. Adopting similar quantitative standards, especially in the by-laws of the KMA, on the provision of green spaces in Kumasi will help city authorities to frequently evaluate the provision of green spaces in the area and hence improve where they fall short in making green spaces readily available.

Extensive tree-planting exercises present another strategy that can be harnessed to increase the amount of green spaces in the area. Almost all the officials from the selected allied bodies on green spaces and many opinion leaders recommended this strategy:

> *The city authorities have to embark on massive tree-planting exercises. The city has lost most of its trees, especially at the CBD and along the principal streets that make the city beautiful. The tree-planting exercise will help to provide many trees in Kumasi. (Official, Environmental Protection Agency)*

> *One measure that can be pursued to improve the lost green spaces in Kumasi is undertaking tree-planting exercises. This exercise should be frequent and involve all the local communities in Kumasi. (Opinion leader, Nhyiaso Community)*

Although some form of tree-planting exercise periodically takes place in Kumasi, the study found that such exercises often lack the active participation of local people. In view of this, a comprehensive tree-planting exercise involving active participation of local people can be pursued by the KMA in conjunction with allied environmental organizations. This can be achieved by informing the local people about the tree-planting exercise in advance, consulting them to learn the various ways they can help, and, on the actual day of the tree-planting exercise, getting them involved by assigning specific roles to them. The active involvement of local people in tree-planting exercises will make them feel part of the undertaking, develop a sense of ownership for the natural vegetation in their areas, and take good care of the natural environment, including green spaces. Implementation of intensive tree-planting exercises with substantial participation of local people has helped a number of African cities such as Durban, Lagos, and Maputo to get approximately 62,000, 500,000, and 2,800 trees, respectively, to enhance their green vegetation (Langer & McNamara, 2011).

Enhancing maintenance of green spaces in Kumasi

Under this strategy, the study found that inadequate funds for regular maintenance works on green spaces is a major problem, and hence having a funding scheme purposely set aside solely for maintenance works on green spaces is essential. This funding scheme can be managed by a team of professionals selected from the allied government and private bodies on green spaces in Kumasi. Some portions of the city’s annual budget could be channelled into the funding scheme. Financial assistance from individual philanthropists, benevolent organizations, and international and local environmental agencies can also be sought to get more funds into the scheme. The managers of the funding scheme, in order to ensure efficiency in the disbursement of funds for maintenance works on green spaces, can take frequent surveys of the available green spaces to get first-hand information on the exact conditions of such spaces, decide on appropriate maintenance works to be applied, and hence allocate appropriate funds to execute these projects.

Apart from lack of funds, poor collaboration between government agencies on green spaces and private organizations was found as another cause of poor maintenance of green spaces in Kumasi. For example, a representative of a private landscape organization had this to say:

> *Private organizations on green spaces, especially those of us who are into horticultural and landscape works, are not much involved by the KMA in their decision-making processes on green spaces. They do not consider us as important stakeholders. This does not motivate us to willingly involve ourselves in the maintenance activities of green spaces. (Manager, private landscape organization)*

In view of this poor collaboration, strong partnership between government bodies on green spaces, private organizations, and local communities is paramount. Frequent invitation of private bodies and local communities by the KMA to participate and deliberate on matters covering maintenance of green spaces can help to address this problem. This effort will help to get more people for maintenance activities on green spaces. Innes and Booher (2004) found this at the heart of collaborative governance, as strong public–private partnership provides a sense of inclusiveness, shared ownership, and a wider network that can be exploited to address a given problem. For example, strong partnership between the KMA and the private sector will provide a wider scope to source funds to embark on maintenance activities. It will also provide an opportunity for the city authorities to out-source some of the maintenance work to private bodies to bring their expertise on board. With respect to the local communities, this will give them a high sense of community stewardship to take the green spaces as their own and contribute in diverse ways to maintaining such spaces.

Institutionalization of an award scheme purposely for green spaces, such as the green flag award in the UK for well-conditioned green spaces, can also be adopted to improve the level of maintenance of green spaces in Kumasi. This recommendation comes in the wake of resentments expressed by the respondents about poor motivation for maintenance of green spaces in Kumasi. For example, some of the respondents noted as follows:

> *The Kumasi city authorities lack vision and foresight to put in place measures to motivate people to maintain green spaces in the various neighbourhoods. The city authorities are just sitting idle and looking at the green spaces get continually destroyed, without doing anything. (Official from the media)*

> *There is nothing beneficial attached to the maintenance of green spaces in Kumasi. If even some neighbourhoods, individuals, or a group contribute immensely to the development and maintenance of green spaces, their efforts are not recognized or rewarded. (Unit committee member, Patasi Community)*

This award scheme can be used as a precursor to get people involved in maintaining green spaces in Kumasi. Specific laid-down criteria which comprehensively cover all aspects of green spaces—such as their attractiveness, comfort, accessibility, safety, level of maintenance, publicity, community participation, and conservation and heritage—can be designed to serve as baseline criteria to select specific parks and other green spaces as winners for the award. This green flag award and the benefits that come along with it, such as opening up areas to boost tourism, pride, and reputation, will serve as incentives to motivate various communities in Kumasi to actively participate in maintaining green spaces in their areas.

Controlling encroachment on green spaces

Under this strategy, addressing conflicting ownership rights on green spaces will be expedient. This can be achieved by compulsory acquisition of and compensation for lands designated for green spaces from the traditional authorities by the government of Ghana. In doing this, a comprehensive engagement/dialogue between the government of Ghana and the traditional authorities of Kumasi will be required. This is synonymous with the principled engagement element in collaborative governance theory that Emerson et al. (2012) stressed as important in addressing conflicts or disagreements among stakeholders to provide successful collaborative outcomes. In line with the principled engagement element, the root problem or concerns of the traditional authorities that influence them to claim ownership of green space lands and release such lands for different land uses in Kumasi should be discovered and addressed accordingly. Following this, serious deliberations between the two parties (government of Ghana and traditional authorities), taking into consideration the concerns of the traditional authorities, could take place. For example, one key informant remarked:

> *The government of Ghana should have to sit down with the traditional authorities of Kumasi [chiefs] and have a fruitful discussion on how most of the green spaces which are in the hands of the chiefs now can properly be reclaimed as a property of the central government. Otherwise, lands reserved as green spaces in Kumasi will continue to be sold for different land uses by the chiefs. (Official, Lands Commission)*

Through dialogue a common agreement can be reached by the two parties for all the green space lands to be acquired by the government of Ghana. This agreement should be sealed by the government of Ghana by signing a memorandum of understanding with the traditional authorities and making arrangements for the necessary compensation to be paid to fully acquire all the green space lands. This arrangement will create fair and civil discourse, open and inclusive communications which have been found by Emerson et al. (2012) and Carlson (2007) to promote collaborative outcomes.

Strict adherence to or implementation of development controls enshrined in the various planning regulations offers a major strategy to control the encroachment on green spaces in Kumasi. This strategy received strong recommendation from some of the key informants (Table 4).

Table 4: Recommendations for enforcement of development controls by key informants

Official, Department of Parks & Gardens	'The city authorities should be firm on the implementation of planning laws. They should not condone any activity that encroaches on lands reserved for green spaces.'
Official, Forest Service Division	'Strong implementation of the planning regulations by the city authorities is the way forward for conservation of green spaces in Kumasi.'
Official, Development Control Unit	'There should be strict enforcement of planning laws. People should not be allowed to build their houses on green spaces.'
Community member, Danyame Community	'Lack of enforcement of land-use regulations is what is destroying the green spaces in Kumasi. To conserve green spaces, the city authorities have to enforce the various land-use regulations.'
Official, Environmental Protection Agency (EPA)	'Some people have taken the planning laws into their own hands and put up houses anyhow to encroach on green spaces. The city authorities have to strictly enforce the planning laws to punish all those people. This will help to conserve many green spaces.'

Source: Fieldwork (2013)

These responses clearly show the extent to which land-use regulations are poorly enforced in Kumasi. Routine monitoring exercises of physical development activities in Kumasi by the Development Control Unit (Works Department), with collaborative efforts by the local people and environmental agencies (such as the Department of Parks and Gardens, EPA, Forest Service Division, and estate agencies), can help to relieve Kumasi of the excessive green space encroachment the city is currently grappling with. Such routine monitoring exercises will help to check whether developers are complying with the regulations and, if not, bring the defaulters to book. It will help the city authorities to easily identify and prevent physical developments that encroach on green space lands, as enshrined in the Local Government Act (Act 462), at an early stage so that they will not degenerate into something worse. Individuals who contravene the land-use regulations should be given a specific time frame to make the necessary corrections; and those who fail to do so should be subjected to the necessary sanctions to serve as a deterrent, preventing others from doing the same. However, this initiative has to be handled fairly and without political interference or favouritism, so that all individuals who encroach on green spaces can be dealt with equally. This will enable the city authorities to demonstrate good leadership skills in their activities and, in turn, motivate the general public to have confidence in them.

Conclusions

The physical barriers to green spaces (conflicting ownership rights, encroachment, and poor maintenance) have denied residents of Kumasi many green spaces that they could rely on for their recreational needs and also led to a situation in which the city now has few parks and gardens. To overcome these physical barriers and enhance the sustainability of green spaces in Kumasi, some strategies were found useful: creation of additional parks and gardens, conversion of brownfield sites into green spaces, extensive tree-planting exercises, and the incorporation of quantitative standards into the provision of green spaces. Other strategies identified were maintenance of facilities on green spaces, institutionalization of an award scheme specifically for green spaces, and strict adherence to planning standards or implementation of development controls to protect green spaces. Using community members to protect designated areas for green spaces, along with the formation of partnerships between public and private organizations on green spaces, could also help to overcome the physical barriers to green spaces in Kumasi.

Implementing all these strategies at the same time will not be feasible in the short term due to the huge tasks required to be met by some of the strategies and the many challenges that have to be overcome. For example, strong financial commitments will be needed to convert brownfield sites into urban green spaces and also to create additional parks to augment the existing ones. A stronger political will will be required, to institute an award scheme for urban green spaces and also to revise some of the town planning regulations to make the regulations more focused on urban green spaces, especially by providing some quantitative standards for these spaces. These efforts are demanding and will require quite a long time for the necessary measures and preparations to be undertaken to achieve them—so they can be considered long-term initiatives. However, in the short term, the KMA can create a strong relationship with local people, private organizations, and civil society organizations in order to implement strategies such as extensive tree-planning exercises, regular maintenance of green spaces, and strict enforcement of development controls to avoid encroachment on green spaces. Even with these strategies, efforts must be made to control uncooperative attitudes of local people and political interference, which may pose key challenges.

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Objective assessment of the Thiessen polygon method for estimating areal rainfall depths in the River Volta catchment in Ghana

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Peter Kwabenah Acheampong

Abstract

Among the problems facing hydro-meteorologists and climatologists is the estimation of rainfall depths at places where there are few or no rainfall stations. A number of models have therefore been developed, evaluated, and recommended by eminent hydrologists and climatology for their applications. These applications are related primarily to specific problems and for the purpose of identifying the most suitable methods for estimating rainfall depths in river basins with very few rainfall records or stations. In this paper, the applicability of the Thiessen polygon method has been reviewed and employed for the purpose of estimating rainfall depths in the River Volta catchment in Ghana. A regression statistic performed to establish the effect of elevation on rainfall distribution in the catchment shows that the former has little or no effect on the latter. The review of the Thiessen method and the results of the analysis of the rainfall field using the polygons show that the method is suitable for estimating rainfall depths in the River Volta catchment in Ghana. The recommendation, however, is that the rain-guage network in the catchment should be improved in other to obtain more but smaller polygons, showing distributions in smaller areas.

Keywords: rainfall depth, rainfall variability, Thiessen polygon assessment

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Introduction

A large number of meteorological and hydrological applications require knowledge about temporal and spatial variability and deficiency of rainfall, especially in areas that have few rainfall stations or rainfall data. The reason, according to Allen and DeGaetano (2005), is that point rainfall data are only applicable for a relatively small area (< 4 sq km).

Rainfall, that liquid water droplet issued from clouds formed by condensation of water vapour in the earth's atmosphere (Acheampong, 2009), plays important role in the hydrological cycles that control water availability, supplies, and water disasters all over the world (Olawoyin, 2015). As such, rainfall and the prosperity of nations go hand-in-hand; without adequate rainfall, both the farmer and the city dweller may not get water to quench their thirst, water their field crops, and carry on with their social, commercial, and industrial activities (ibid.).

Hence, too much or too little rainfall in an area is a major barrier to the area's wider economic development. And yet, it is not just the direct impact that reduces productivity of farmlands or renders manufacturing industries impossible. There are also indirect costs, such as poor health, hunger, and poverty, which are caused by floods and droughts that reduce productivity in places all over the world. For example, a sudden heavy downpour in a short period of time may cause severe flooding, loss of life, and the destruction of properties (Andoh et al., 2015) in towns and cities and in places where there are no recording gauges. As such, the need to identify ideal methods for estimating the minimum and maximum rainfall depths in all places and countries, including Ghana — and in particular the Volta River catchment (RVC) — for socio-economic planning and development cannot be overemphasized.

Rainfall data in Ghana are collected using rain gauges at weather stations located at agricultural stations and at the Ghana Meteorological stations in the district and regional capitals. Such data are point values. But the use of a single or a few rain-gauge data as rainfall inputs for large areas such as the RVC carries huge uncertainties regarding, for example, overland-flow and runoff estimates (Faur'es et al., 1995; Firdaus & Talib, 2014). This presents major problems for the prediction of discharge, groundwater level, and soil moisture, especially where there are few or no recording rain gauges (Schuurmans & Bierkens, 2007).

Against the above background, applications such as rainfall mapping (Aronica & Ferro, 1997; Goovaerts, 1999; Angulo-Martinez & Begueria, 2009) and hydrological modelling (Kobold & Suselj, 2005; Cole & Moore, 2008) require rainfall data that come from dense and spatially continuous rain-gauge networks. In other words, to estimate rainfall depths properly for large or small areas (that have few rainfall stations or data), there is the need for optimally distributed rain gauges. Where this is not applicable, there is the need to apply the most appropriate models for estimation (Chahouki et al., 2014).

Problems such as rainfall variability and deficiency in Ghana, and especially in the RVC (which contains the Volta Lake and dams), are challenges that can be solved only by estimating the minimum and maximum rainfalls in many places. This is why it is absolutely critical to use the most appropriate method for estimating rainfall depths in the river's catchment.

The three well-known alternative techniques identified in the literature to improve the accuracy of areal rainfall depth estimation are the arithmetic mean, the isohyetal model, and the Thiessen polygon method (Olawoyin, 2015). In this paper, the Thiessen polygon method is considered. The arithmetic mean and the isohyetal methods are considered in subsequent papers. The goal of the present paper is to resolve some of the disagreements on the application of the Thiessen polygon method as far as the conditions in the RVC are concerned, and to justify its use for estimating areal rainfall depths in the catchment.

The Thiessen polygon

The Thiessen polygons (Figure 1), also known as Voronoi networks and Delaunay triangulations, were discovered in several fields, including climatology, as an essential method for the analysis of proximity and neighbourhood of phenomena, over a century ago. This method is a graphical technique that calculates station rainfall weights based on the relative areas of each measuring station in the Thiessen polygon network. The method proposed by Thiessen (1911) assigns to each rain-gauge station a weighted value based on the percentage of the area it represents in relation to the total area of the region in question. The areal rainfall depth of the region derived by the method then represents a weighted depth. For the above assertion, Wiesener (1970) says that the Thiessen or areal weighting method weights each station's rainfall value according to the area which is closer to the recording station than any other. This area is obtained by drawing perpendicular bisectors on lines joining nearby stations to form a series of polygons, each containing one and only one rainfall station, and leaving the other stations in the centre of polygons which will vary in size according to the spacing of the gauges (Figure 1). The percentage of the total area (of the place) represented by each polygon or part of it is determined by planimetering or by other methods, and is applied to the appropriate station's or rain-gauge total. The model is mathematically given as follows:

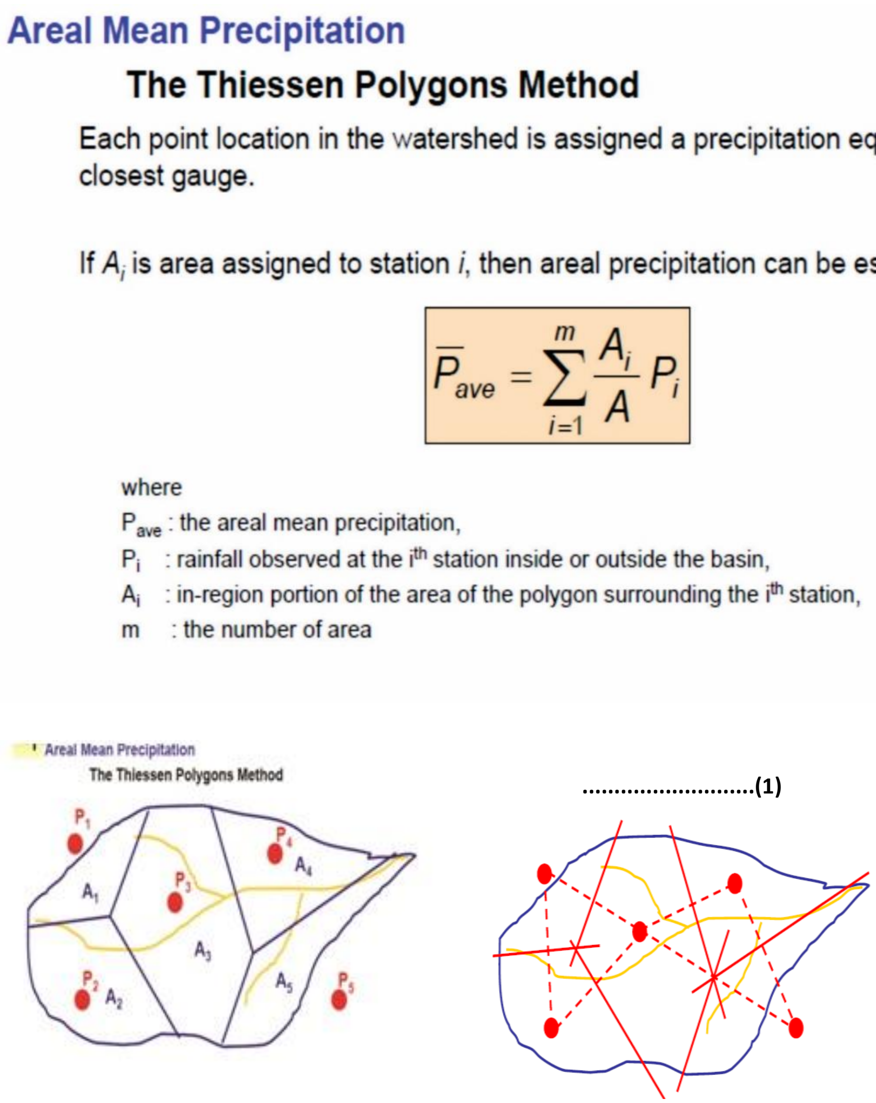

Figure 1: Steps for the determination of the Thiessen polygon method

Objective assessment of the Thiessen polygon method for estimating areal rainfall depths in the River Volta catchment in Ghana

Source: Akintug (n.d.)

To determine A_i

- All adjacent station locations are joined by straight lines.
- Perpendicular bisectors of the lines are drawn.
- The bisectors are extended to form polygons around each station.
- The area of each polygon is multiplied by the rainfall value of the station that is inside the polygon.
- The values obtained are added and then divided by the total catchment area to get the weighted rainfall.

One of the assumptions of this method is that linear rainfall gradients exist; hence, many researchers recommend that the use of the method should be restricted to relatively flat areas with linear rainfall distribution. Arguments remain, however, concerning the optimal gauge density and spacing conditions for its application. Several authors recommend the method's use for areas characterized by a relatively dense and uniformly spaced rain-gauge network. Weisner (1970), for example, considers that the method is satisfactory with even rainfall distribution, a good gauge network, and flat country. Edwards (1972) also says that the method is most applicable in densely gauged networks.

Contrary to the above observations, others recommend the method's use for sparse and unevenly spaced networks. The World Meteorological Organisation (WMO, 1965), for example, declared that the Thiessen polygon method was suitable for non-uniform station spacing. Bruce and Clark (1966) observed that the method has several advantages for places with relatively few rain gauges unevenly distributed geographically, while Ward (1969) held the view that the method even made some allowances for uneven distribution of gauges, because it enabled data from adjacent areas to be incorporated in the mean. Although studies addressing the relative accuracy of the Thiessen method are not many, some, such as Horton (1923), say that compared with the arithmetic mean method, for example, the Thiessen method is more accurate for a sparser network, and that the method will always give reasonable results if the variability among the rainfall data is not too large.

Methods

The study area

The study area (Figure 2) is the RVC in Ghana. It covers approximately 160,169.85 sq km in the Ashanti, Brong Ahafo, Eastern, Volta, Upper East, and Upper West regions. The Akosombo Dam is located at the downstream end of the catchment, while the Bui Dam is in the west. The RVC was chosen for four reasons: its vast socio-economic importance (e.g. the Bui and the Akosombo dams, the Volta Lake, the generation of hydro-electricity, irrigation, and tourism); poor rain-gauge network; availability of reliable rainfall data (though from few rainfall stations); and its rich agricultural lands, which vary in altitude from just 122 m to over 300 m above sea level. The area consists mainly of the Voltaian sandstone basin; the rest is a series of escarpments at different heights (for details, see Acheampong, 2009).

The climate of the RVC is tropical (ibid.). The mean temperatures are high and seldom fall below 25 ^{o}C. The weather patterns are dominated by the north-easterlies or Harmattan airflow, which brings in its wake dry, desiccating, cool winds during the dry season (November–April); the south-west monsoon winds, which bring monsoonal rainfall between May and November; and the equatorial easterlies, which are associated with disturbance lines, vortices, and thunderstorms that occasionally produce heavy and copious rainfall at the beginning and the end of the rainfall season. Rainfall decreases from the south and the east towards the north (Figure 3). South of latitude 7^{o}N, there is a double maximal regime; the north has a single maximum (Acheampong, 2014).

The vegetation of the RVC consists of the interior Guinea savannah sub-zone and the Sudan savannah. The dominant vegetation in the interior savannah includes the baobab, the dawadawa, shea, and tall grass. The Sudan savannah has trees with fine-leaved, thorn-less species. The dominant plants are tussock grasses, which form almost continuous cover even beneath trees, especially during the rainfall season.

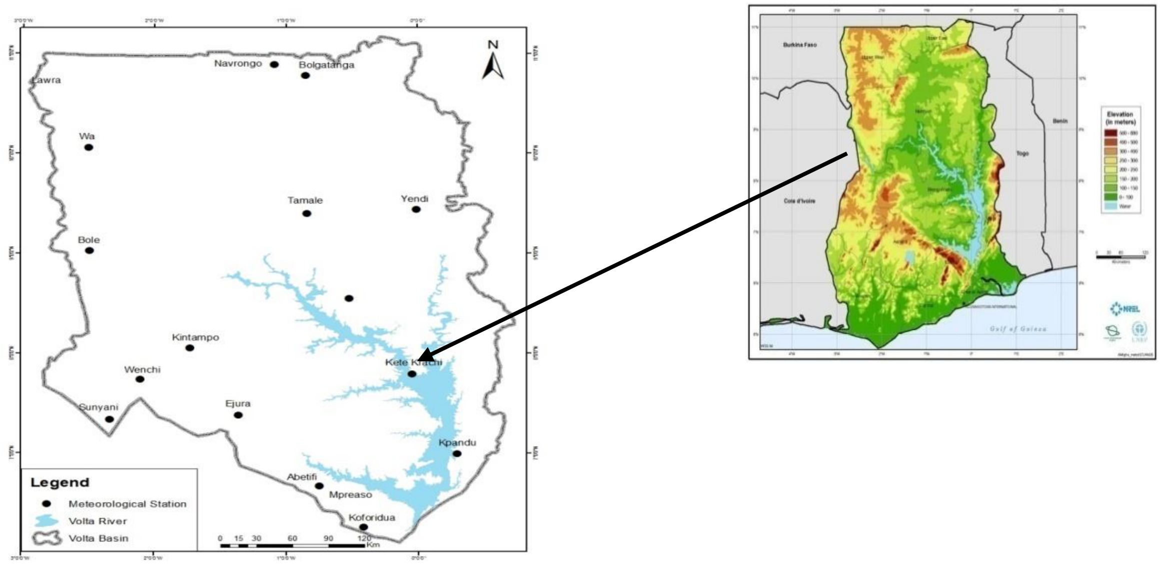

Figure 2: The study area: River Volta catchment

Source: Computer-generated map (2015)

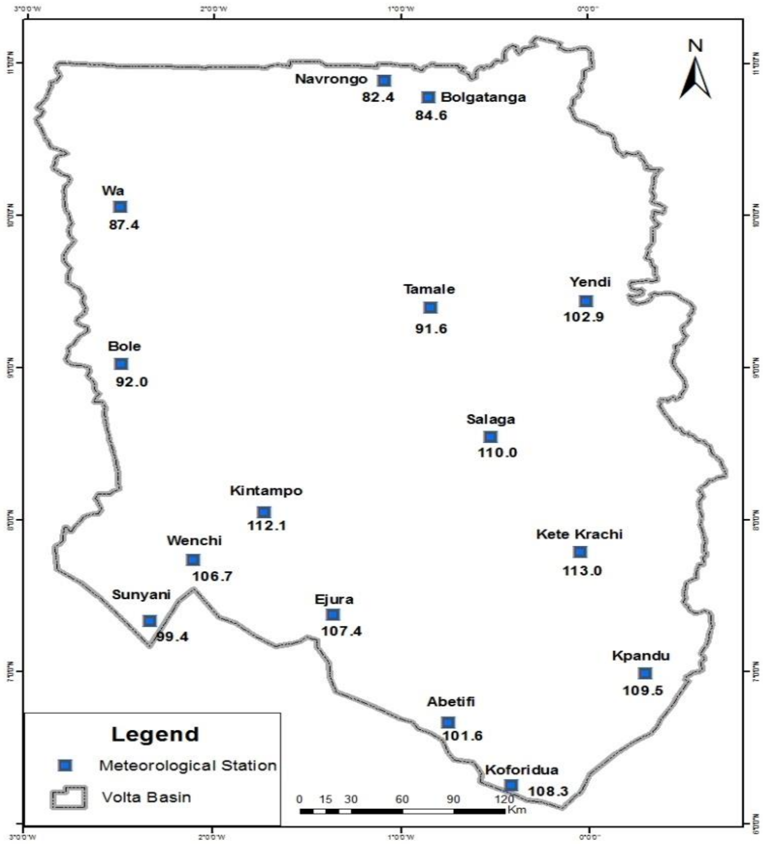

Figure 3: Rainfall distribution over the Volta catchment

Data and source

The monthly rainfall data (Table1) employed were collected from the records of the Ghana Meteorological Agency in Accra, for the period 1982–2012 for 15 recording stations. The choice of the period was due to the availability and continuity of data. The consistency of the rainfall data was investigated through the study of weather records, which were the following:

- *Hyetographs*: These were the original daily rainfall charts obtained from self-recording rain gauges. Black continuous or broken lines on this chart gave both the amount and the duration of rainfall recorded during a particular period.
- *The daily weather (MET and 101):* This file provided the statistical summary of the weather at each station as well as for given synoptic hours for each day of the month.

- *The summary of daily weather*: This contained the synoptic weather stations for the whole of West Africa, with particular reference to Ghana, for each day of the month.
- *The monthly report of work*: This provided the monthly summary of the weather.
- *The annual summary of observations in Ghana*: This gave the statistical summary of the weather elements at all the stations for each month of the year.
- *The Kalamazoo***:** This was the register which contained the rainfall data for each day of the year.

Table 1: Average annual rainfall amount from rainfall stations 1982–2012 (30 years)

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Total**	**Avg**
Abetifi	16.2	35.8	113.7	136.2	153.4	197.5	97.4	83.6	158.6	154.4	47.2	25.0	1218.9	101.6
Bole	2.4	11.5	45.0	105.4	131.0	152.7	143.8	167.2	213.8	107.8	18.0	5.8	1104.5	92.0
Bolgatanga	0.2	2.5	12.3	43.1	113.6	141.3	176.1	268.4	189.9	59.1	5.6	3.5	1015.5	84.6
Ejura	7.1	25.0	90.5	150.4	168.7	188.9	129.9	88.9	209.2	172.4	38.1	20.3	1289.3	107.4
Kete-Krachi	6.4	11.1	34.7	94.8	129.1	216.2	211.1	222.4	252.4	149.1	21.8	7.1	1356.2	113.0
Kintampo	5.9	24.4	73.0	143.0	162.6	194.7	152.5	136.7	223.6	180.7	35.9	12.3	1345.3	112.1
Koforidua	22.9	62.9	110.0	147.1	158.0	192.4	120.0	88.1	140.6	159.4	68.5	29.8	1299.7	108.3
Kpandu	6.9	29.9	68.9	132.0	140.4	184.6	199.9	167.8	174.6	148.3	46.6	14.0	1314.0	109.5
Navrongo	0.0	2.3	11.8	52.6	104.1	141.5	182.7	274.3	166.7	48.5	2.5	2.1	989.2	82.4
Salaga	6.7	10.8	48.8	122.8	119.9	191.4	178.3	214.5	265.0	141.2	12.6	7.4	1319.5	110.0
Sunyani	8.3	41.0	101.5	150.1	144.6	192.7	97.1	68.9	161.6	165.2	45.1	17.1	1193.2	99.4
Tamale	3.1	10.0	32.6	87.5	118.0	149.4	173.3	192.3	215.4	93.5	8.1	4.2	1087.3	90.6
Wa	4.5	6.2	20.8	87.2	126.5	147.0	154.9	221.1	196.3	77.2	5.0	1.8	1048.4	87.4

Wenchi	7.7	26.3	100.8	160.6	173.6	158.9	128.2	98.6	184.9	177.2	50.7	13.1	1280.7	106.7
Yendi	3.6	8.4	46.5	93.6	120.6	175.2	181.5	231.0	262.6	102.9	6.3	2.7	1234.8	102.9
Total	102.0	308.1	910.8	1706.3	2064.2	2624.5	2326.7	2523.7	3015.2	1936.9	411.9	166.2	18096.5	1508.0
Average	6.8	20.5	60.7	113.8	137.6	175.0	155.1	168.2	201.0	129.1	27.5	11.1	1206.4	100.5

Source: Ghana Meteorological Agency (2015)

Missing data

Trace mean monthly rainfall amounts flagged as accumulation in a month were assumed missing or invalid as data values in the archived data. Stations included in the analysis were required to have records that spanned the period 1982–2012, with no year completely missing during this interval. Using this strategy, Bawku and Lawra, which have several years' rainfall data missing, were not included in the analysis. The available rainfall data at 15 rainfall stations were therefore collected for the analysis.

The location of the 15 stations did not follow any particular pattern. They appear to be dictated by the location of the meteorological stations that are cited in the regional capitals, such as Tamale, Wa, and Bolgatanga, and in other large settlements such as Ejura, Kintampo, Navrongo, and Bawku, which also serve as district capitals. As a result, the gauge network is very sparse. Much of the central and the northern parts do not have gauge coverage. Whereas most of the stations are found in the south, the rest of the catchment area is coarsely served. The number of rainfall stations located in the catchment area is shown in Table 2 and in Figure 3. Also presented in Table 2 are the altitudes (heights or locations of stations above sea level), the annual mean rainfalls for the 30-year period, and the coordinates of the stations.

Table 2: Rainfall stations in the River Volta catchment area, their altitude above sea level, coordinates, and mean average rainfall for the period 1982-2012

Rainfall stations	Latitude	Longitude	Altitude (m)	Rainfall (mm)
Abetifi	05°47'00"N	000°38'00"W	601	101.6
Bole	09°02'00"N	002°29'00"W	264	92.0
Bolgatanga	10°47'00"N	000°51'00"W	581	84.6
Ejura	07°23'00"N	001°21'34"W	228	107.4
Kete-Krachi	07°49'00"N	000°02'00"W	87	113.0
Kintampo	08°03'00"N	001°43'00"W	286	112.1
Koforidua	06°05'00"N	000°15'00"W	87	108.3
Kpandu	06°60'00"N	000°17'00"E	152	109.5
Navrongo	10°54'00"N	001°06'00"W	197	82.4
Salaga	08°33'00"N	000°31'00"W	163	110.0
Sunyani	07°20'00"N	002°20'00"W	308	99.4
Tamale	09°25'00"N	000°51'00"W	151	90.6
Wenchi	07°45'00"N	002°06'00"W	304	106.7
Wa	10°04'00"N	002°31'00"W	305	87.4
Yendi	09°27'00"N	000°01'00"W	157	102.9

Source: Ghana Meteorological Agency (2015)

N = north of equator, W = west of longitude 0, E = east of longitude 0

The ordinary rain gauges (Snowdon types) used to measure rainfall depths in Ghana are exposed, ground-levelled, and installed with their rims parallel to the slope. Rodda (1970) and Sevruk and Hammond (1984) have shown that ground-level gauges to be the most efficient collectors.

Data processing

In order to meet the study objectives, some rainfall estimation model software programmes (McGuiness, 1963; Forest, 1980; Guillermo et al., 1985; McCuen & Snyder, 1986; Singh & Chowdhury, 1986; Majeed, 2002; Faisal & Gaffer, 2012) were reviewed, and some were considered as integrated solutions to the catchment rainfall estimation. In this work, the Thiessen polygon method described above was carried out by applying the nearest neighbour method in the Arc View GIS software (version 10.1) which was developed by the Environmental Systems Research Institute (2002) and used by Taesombat and Sriwongsitanon (2009). Input data consisted of the stations' coordinates, the monthly rainfall values from the 15 stations, and the names of the observed locations. The outputs from the Arc View GIS software were area rainfall surfaces which corresponded to the Thiessen polygon network.

Before presenting the full results of the analyses, however, details of the computer programmes that were used for the computations are provided in order to illustrate more fully the methods employed. The regression analysis is first described.

Data analyses

Investigation of altitude effect on rainfall depths in the RVC

A regression analysis (Equation 2) was performed to ascertain the effect of altitude on rainfall distribution in the RVC. The reason was that rainfall depths normally vary in space and in time (Goovaerts, 1997), and they tend to increase with increasing elevations, because of orographic effect of mountainous terrain, which causes air to be lifted vertically so that condensation occurs as a result of adiabatic cooling (Acheampong, 2009). Hevesi et al. (1992a) and Hevesi et al. (1992b), for example, obtained a significant correlation of about 0.75 between average annual precipitation and elevation in Nevada and in south-eastern California, in the United States.

To investigate whether this observation occurs in the RVC, the mean rainfall data of the stations were regressed against their altitudes above sea level using the equation:

$$Y = \alpha_o + \alpha_1 h_1 + \varepsilon \quad (2)$$

where Y is rainfall,

α_o is intercept,

α_1 is the coefficient of altitude,

h_1 is the altitude (location of rainfall station above sea level),

and ε is an error term.

In using this method it was assumed that a linkage between the two parameters would mean it is possible to increase the accuracy of area rainfall interpolation by applying a topographic parameter (ground elevation of rainfall station) (Hastings & Dunbar, 1998; Goovaerts, 2000; Gorokhovich & Voustianiouk, 2006).

Analysis of the RVC rainfall using the Thiessen polygon

The Thiessen polygon (Equation 1), as noted already in this paper, is a method of using rain-gauge network (see Figure 1) for estimating watershed average rainfall depths, which is especially suitable for electronic computation (Diskin, 1969; Diskin, 1970). As in the hypothetical figure (Figure 1) taken from the US Department of Agriculture National Engineering Handbook (1993), the Volta basin was divided into sub-areas using the stations as hubs of polygons. The sub-areas were used to determine ratios that were multiplied by the sub-area rainfall and summed to get the watershed average rainfall depth. The ratios, as observed earlier in this paper, were therefore the percentages of areas in the basin presented by each station. Figure 4 shows a polygon diagram of the rainfall distribution in the RVC in Ghana.

Results

Altitude effect on rainfall depths

The results of the simple regression analysis of the annual totals from all the15 stations against their elevation are shown in Tables 3 and 4, and in Figure 4. Although the coefficient of determination is positive (0.139), the relationship is very weak. The implication is that elevation or height has very little influence on rainfall distribution in the catchment area, and hence did not feature in any subsequent computation.

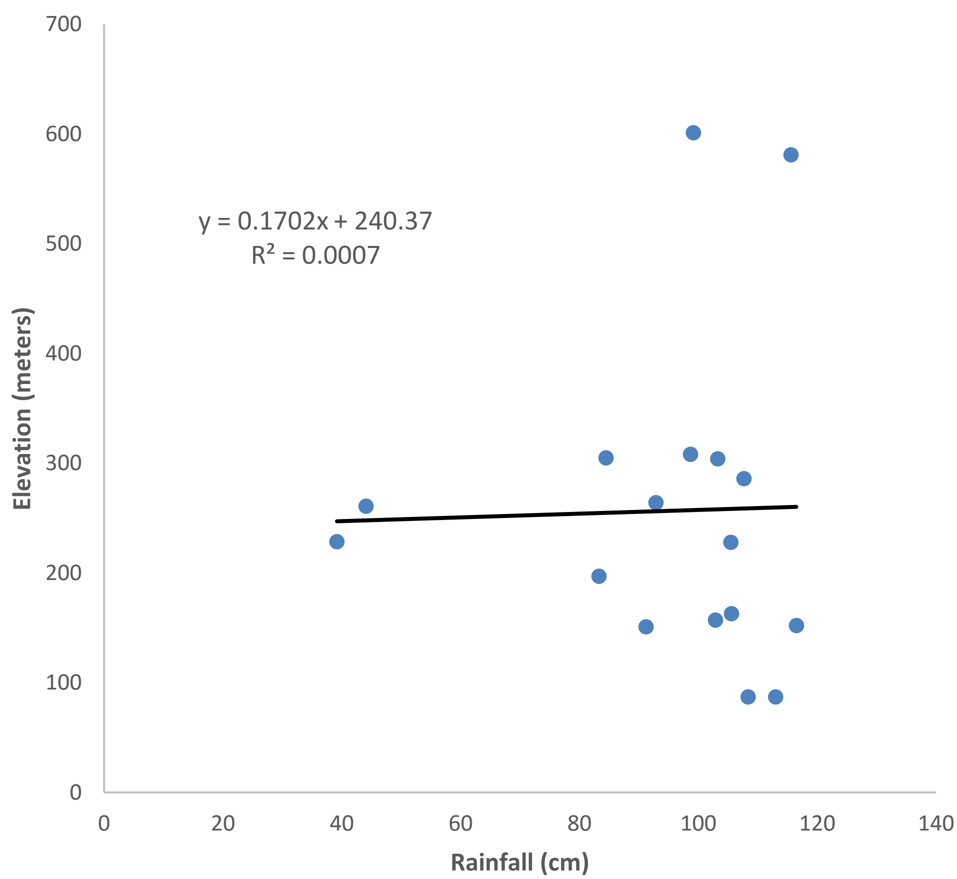

Figure 4: Altitude effect on rainfall distribution in the study area

Source: Result from regression analysis (2016)

Table 3: Residual output of regression analysis

Observation	***Predicted Y***	***Residuals***	***Standard residuals***
1	252.3462	348.6538	2.430821
2	304.8341	-40.8341	-0.2847
3	345.6687	235.3313	1.640734
4	220.0606	7.939445	0.055354
5	189.3591	-102.359	-0.71365
6	194.3648	91.63519	0.638882
7	215.2546	-128.255	-0.89419
8	208.6955	-56.6955	-0.39528
9	357.7291	-160.729	-1.12061
10	206.2049	-43.2049	-0.30123
11	264.1299	43.87013	0.305863
12	312.7328	-161.733	-1.1276
13	330.585	-26.585	-0.18535
14	223.9909	81.00908	0.564797
15	245.0439	-88.0439	-0.61384

Source: Computer-generated result (2016)

Table 4: Summary output of regression analyses

Regression Statistics								
Multiple R	0.373268							
R Square	0.139329							
Adjusted R Square	0.073123							
Standard Error	148.8449							
Observations	15							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	1	46624.59	46624.59	2.104492	0.170566			
Residual	13	288012.3	22154.8					
Total	14	334636.9						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	811.5749	383.4797	2.116344	0.05418	-16.8827	1640.033	-16.8827	1640.033
X Variable 1	-5.50557	3.795151	-1.45069	0.170566	-13.7045	2.69335	-13.7045	2.69335

Source: Computer-generated result (2016)

Thiessen polygon map of the mean areal rainfall in the River Volta catchment

As stated earlier in this paper, the Thiessen polygons were used to create initial territorial boundaries for each of the rainfall stations. The polygons so obtained involved the division of the catchment area into a number of separate territories, each of which focused on a separate or single station. The simple Thiessen polygons map (Figure 5) is therefore a territorial distribution of mean annual rainfall (MAR) that suggests lack of ranking. The polygons in the south and south-east are more clustered together and also have larger MAR values.

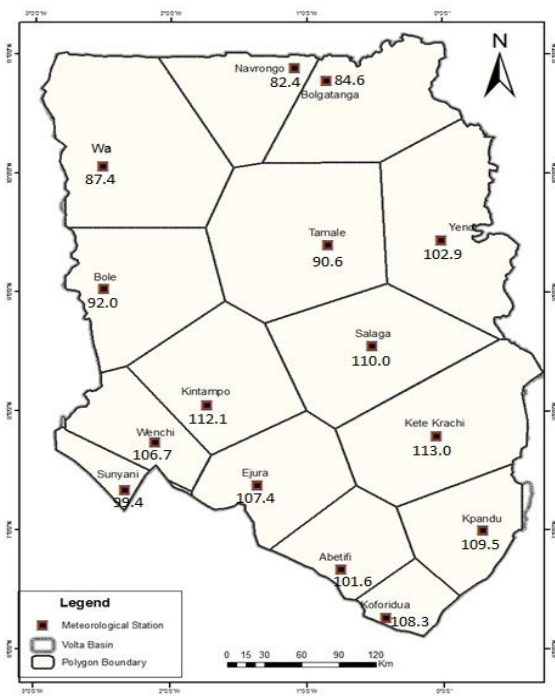

Figure 5: Thiessen polygon map showing mean annual rainfall depths in the River Volta catchment

Polygon mean of catchment = 93.0cm

Source: Computer-generated map, 2016

Those polygons in the rest of the catchment that have low MAR values are not clustered together. For example, Wa, Tamale, Salaga, and Yendi have low MAR values that are 87.4 cm, 91.6 cm, 110.0 cm, 102.9 cm, respectively, but because of their great distances from other stations, have large polygon sizes, which are 18,892.20 sq km, 17,770.90 sq km, 16,736.78 sq km, and 14,917.48 sq km, respectively. These polygons occupy 11.8%, 11.10%, 8.61%, and 9.31% of the catchment, respectively. On the other hand Sunyani (99.4 cm), Abetifi (101.6 cm), and Koforidua (108.3 cm) have high MAR values, but because of the proximity of several rainfall stations they have small Thiessen polygon sizes of 2,322.22 sq km, 6,736.78 sq km, and 3,385.03 sq km, respectively. The areas occupied by the three stations are 1.45%, 4.21%, and 2.11%, respectively. These findings suggest that a Thiessen polygon area alone is not sufficient to infer territorial importance. The catchment mean using this model is 93.0 cm.

Summary conclusions and recommendations

The research sought to find the applicability of the Thiessen polygon method, as recommended by eminent hydro-meteorologists and climatologists, for the purpose of estimating area rainfall depths in the RVC in Ghana. The rationale behind the search was multi-faceted. One of the most important weather and climate elements in Ghana is rainfall, which is the source of water for most socio-economic activities. Not only is rainfall (water) essential for agriculture, it is also the driving force behind the generation of hydro-electricity at Akosombo and Bui. However, rainfall's variability and deficiency sometimes cause drought or floods, and not enough water in the Volta Lake to drive turbines to produce the needed electricity for domestic and industrial use. There was therefore a need to know, and also estimate, the mean rainfall amounts that are near the real values in those places in the catchment where rain-gauge networks are among the poorest in the country.

The RVC in Ghana was selected for the study because of its socio-economic importance to the country. The catchment covers more than half the surface area of the entire country. Economically, it is the least developed, but it has immense (economic) potentials. For example, much of the grain crops such as maize, millet, and sorghum, tuber-crops such as yam, and vegetables such as beans, onion, tomatoes, and groundnuts produced in Ghana come from the farmers in this area. Most importantly, the area has the Volta Lake, whose waters are used to generate hydro-electric power for Ghana and the neighbouring countries.

In spite of the socio-economic potentials of the region, the RVC in Ghana is poorly served with rainfall stations; consequently, the actual quantities of rain that fall over the different locations in the catchment are unknown. There was therefore the need to search for efficient techniques that could be used to estimate the mean rainfall depths over the area. This was important because road or civil engineers, for example, need to know the minimum and maximum rains that fall at several other places in order to obtain the right measurements of culverts or drains that can efficiently carry flood waters into the Volta Lake, and eventually into the sea. The Ghana Electricity Company, for example, needs to know how much rain falls over every place in the catchment throughout the year. The return periods of extreme events such as meteorological drought and floods should be known so that the dams that are being proposed for future construction can be made large enough to have the capacities to hold large volumes of water for the generation of hydro-electric power even during the dry months.

A search through the studies that had been conducted on the estimation of rainfall depths at the earth's surface elsewhere revealed that though a few other techniques exist or are being used to estimate rainfall depths, the Thiessen polygon model is among the best, most popular, and most straightforward method for estimating rainfall depths. Although the literature acknowledges the fact that the method has certain weaknesses, its strength makes it ideal for estimating rainfall depths over different terrains, and especially in the RVC in Ghana.

Mean monthly rainfalls from the available 15 synoptic stations for a 30-year period (1982–2012) in the catchment area were employed. This period's mean values are accepted by the World Meteorological Organisation to represent the average falls over the area (Acheampong, 2009). The gauge network is considered very thin and poor, and suggestion is being made for the establishment of additional stations to make the gauge network dense in the region so that more readings can be taken at close intervals. This suggestion has been found necessary because the nature of tropical rainfall is such that a sudden copious rainfall, even in the dry season, may occur in a day at a non-recording location nearby and may cause severe flooding.

The height or altitude of the rain gauges above sea level and their coordinates were fed into a computer, and using some well-known computer programmes, the Thiessen polygon map was drawn. The results of the analyses, as has been noted, show that altitude has very little effect on rainfall distribution in the catchment, and that the Thiessen method is suitable, at least for the moment, for analysing rainfall data for the study area.

The map showing point values gives the rainfall at points that represent vast areas. Such a result is unacceptable, for example, for planning purposes. The Thiessen polygon method was therefore used to create territorial boundaries for each of the rainfall stations. The polygons so created involved the division of the catchment into a number of separate territories, each of which was focused on a single rainfall station.

The findings and conclusions from this particular area may be different from the findings from other regions in Ghana if the same methods are employed, because of the differences in terrain and in density of rain-gauge networks. For these and other reasons, it may be necessary for the research to be replicated in other catchments in the country that have potentials for irrigation projects and the harnessing of their rivers and streams for hydro-electric power. So far as the RVC study is concerned, the Thiessen polygon method is applicable. It appears that the method will become more accurate as the gauge distribution in the catchment becomes more nearly even.

Another area worth researching is the estimation of rainfall depths using other methods, such as radar, triangular facets, revised weighted polygons, and height-balanced polygons, which have been successfully used elsewhere, but so far have not been tried in Ghana.

Finally, the method could be used to estimate other climate elements such as humidity, evaporation, and potential-evaporation in river catchments in Ghana. Gauge network parameters should be included in such studies as significant factors, and such studies should make use of both simulated and real data sets. A product which can be envisioned from this type of research would be a rating system for all available areal rainfall assessment methods, in which the accuracy of each method is established on an either absolute or relative scale.

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